CONTROL

SYSTEMS · INSTRUMENTATION · DATA PROCESSING · ENGINEERING · APPLICATIONS

VOL 2 NO 8 FEBRUARY 1959

SPECIAL FEATURES

REGULAR FEATURES

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PUBLISHER'S COLUMN

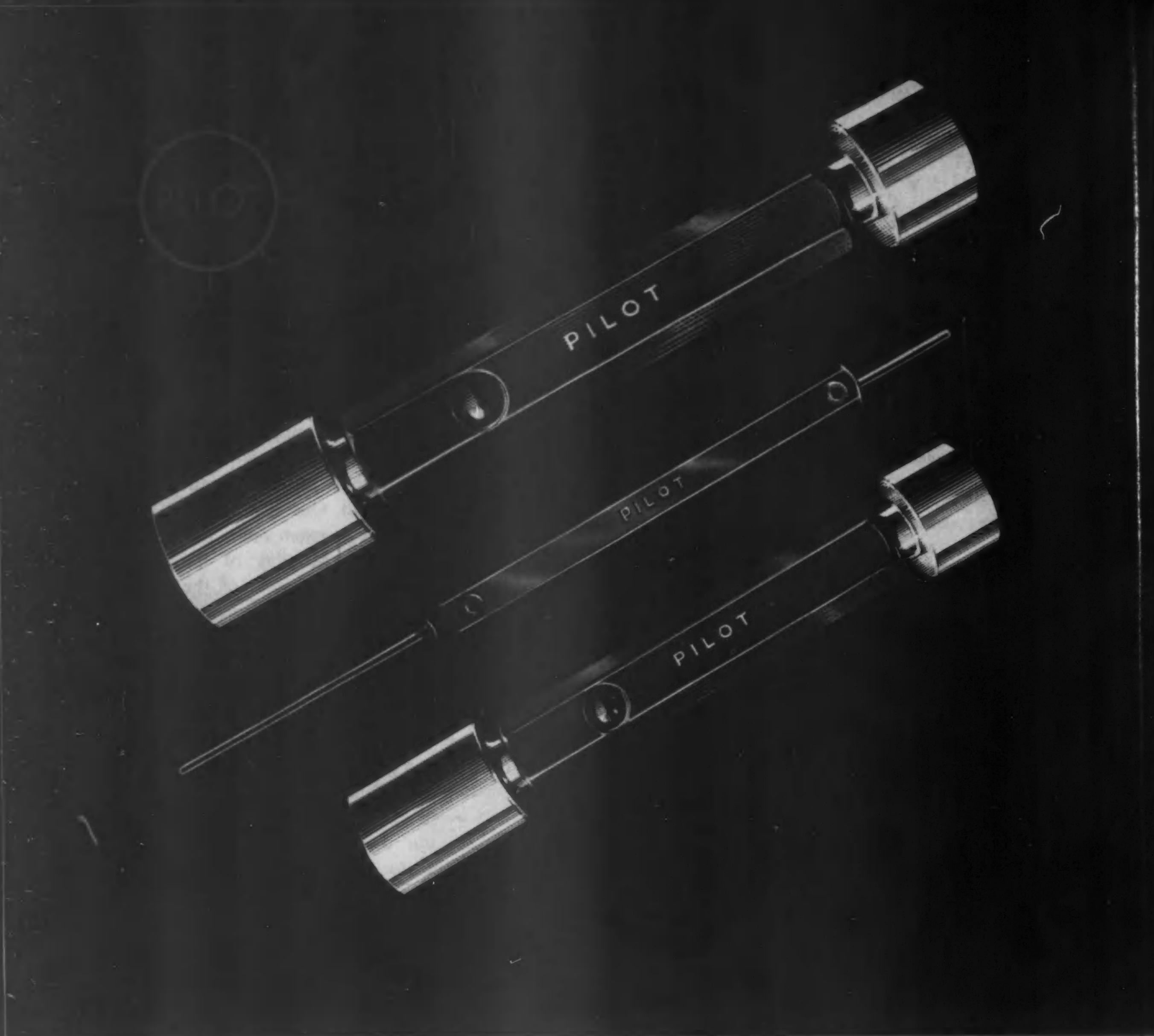
FORTY FEET LONG

Less than three weeks ago a visitor for **CONTROL** arrived clutching a roll of paper about the same general dimensions as a Dead Sea Scroll. Upon unwinding it it was revealed as nearly 40 ft long. This was rather apt as it contained complete technical specifications of—we hope—every potentiometric chart recorder manufactured in Britain. Our visitor, and compiler of this *magnum opus*, was of course C. W. Munday of the Instrumentation Department of the Distillers Company. The results of his labours can be seen in the *Control Survey* beginning on page 80. When our printers saw this vast piece of 'tabular copy' they were horrified, but we are sure you'll agree they have done a good job in setting it.

Munday's *Control Survey* is the first we've published compiled from outside our own organization and we'd like to thank him for the immense trouble he has taken over it. Believe us, we know what it involved! It is also the first *Control Survey* to include a short explanatory article, which we think will help many readers.

These surveys are primarily of interest to instrument users and Munday, representing a user interest himself, is in an excellent position to understand their needs. Furthermore he holds no brief for any particular manufacturer, all of whose products have been judged impartially.

What we have here is a new approach to the old problems of manufacturer-user relationship and this we feel is a cardinal point in modern business-technical-magazine journalism. We hope Mr Munday's article and his 40 ft of tabulation—now so conveniently boiled down—will clarify for some time at least the situation as regards British potentiometric chart recorders.


PILOT
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Sir! LETTERS TO CONTROL

Imperative need

SIR: Automation can free workers from menial tasks and enable them to apply themselves to work of greater complexity, perhaps during a shorter working week: this can dignify labour rather than cheapen it. However, such benefits are likely to be seriously delayed owing to a shortage of control engineers; this exists now and will become much more serious in the next decade.

An urgent need exists for training schemes to produce control engineers and technicians to design, maintain and install control systems. At present courses available are woefully inadequate, partly owing to lack of vision, partly to lack of lecturers.

Here industry could assist by releasing engineers for teaching during the day and by producing some of the complex special purpose equipment needed. This requires taking a long-term view, but if rapid assimilation of control system techniques by industry is to occur some immediate and effective action is imperative.

Wimbledon Technical College N. G. MEADOWS

● *Thank you, Mr Meadows. When far-seeing people like yourself have gone on saying this long enough, the state of control engineering training in Britain will begin to improve. Canada and the USA are doing better: see Dr Porter's letter on p 61*—EDITOR

Why not British?

SIR: Referring to Mr Fielden's article in the December issue of CONTROL, I agree that the British instrument industry will never catch up with American practice by taking up licences to manufacture American instruments. There is no shortage of new ideas in this country, but there is often considerable delay in getting new ideas for instruments translated into practice. Gas chromatography provides a recent example.

The British instrument industry would have more chance of 'catching up' if attention were paid to the following points:

1. Greater effort to be made to satisfy the needs of the customer. Closer liaison between manufacturer and user is indicated
2. A wide range of intrinsically safe instruments should be developed
3. A detailed and guaranteed minimum specification of the instrument performance should be published by the manufacturers
4. Instruments must be designed to function under plant conditions
5. Prompt and adequate after sales service to be provided—at least as good as the best American practice
6. Delivery dates to be maintained
7. Traditional British reputation for good mechanical design, robustness, simplicity and good workmanship must be upheld

London, SE9 C. W. MUNDAY

No go if you are not going

SIR: I see that my January copy of CONTROL includes a foretaste of the Physical Society Exhibition, which is under way in Westminster as I write. It is an excellent review, but, to my mind, almost valueless. Surely this sort of thing is only useful to instrument specialists —and, presumably, they will attend the exhibition anyway. What most engineers need is something summarizing present instrument trends and picking out a few outstanding examples from the show. This will teach them something whether they go there or not.

Manchester R. H. DAY

● *We like the idea of a 'trends' article, though we suspect the general pattern of movement would be about as clear as that of the traffic at Hyde Park Corner in the rush hour. But, Dr Day, who would be rash or wise enough to pick out a few outstanding examples from such a wealth of new instrument development? Send us his name, please*—EDITOR

Continued on page 61

Sir!

Continued from page 59

A CANADIAN LETTER

Dr A. Porter, Dean of Engineering at Saskatchewan University, Canada, will be writing reports on control events in Canada for publication in CONTROL *from time to time. Here is the first:*

Although a few months in Canada is scarcely adequate to assess general trends in control systems technology, several features seem to me noteworthy. First, the application of transistors and other solid-state devices as basic components in communication and control circuits is becoming widespread, and the concept of the small packaged circuit has been adopted almost universally. Secondly, there has recently been a notable increase in the number of good textbooks covering all aspects of control systems synthesis and design. Thirdly, control systems technology is now a recognized undergraduate subject for aeronautical, chemical, mechanical, and electrical engineering courses.

Transistors move in

Indication of the rapidly increasing importance of transistors, germanium and silicon diodes, etc, in electronics was provided at the IRE Toronto Convention last October when approximately half of the papers presented were concerned with solid-state devices and their applications. Although most applications described were from communication, or computing and data-handling, systems, the design of transistor amplifiers for servo systems received considerable emphasis. The limited power requirements, compactness, and undoubted reliability of these circuits are particularly attractive features which will go a long way towards breaking down in certain industries the inherent suspicion of all electronic control equipment. My general impression is that with the increasing need for reliable data-logging equipments in chemical plants, refineries, etc, electronic systems, essentially transistorized, will tend to replace many of the existing pneumatic data-transmission and control systems.

Not only for *electrical* engineers

To keep pace with the growing demand for control system technologists, most Canadian universities have introduced both undergraduate and postgraduate courses in automatic control, and several strong research groups have been established in the field. The standard of these courses is somewhat lower than the equivalent courses at present being given at Imperial College and other engineering schools in the United Kingdom. However, I must stress that the Canadian courses are provided for engineers as a group rather than for specialists in light electrical engineering. This means that much material is concerned with hydraulic and pneumatic control systems and also with the general problem of regulation in chemical plants. Although postgraduate courses and research facilities are available in the Canadian universities for advanced study in automatic control and related fields, there is nevertheless a strong urge for engineering graduates to undertake their higher degree work at one of the well-established United States automatic control laboratories. Of special note is the increasing scope in the activity of the MIT Servo Laboratory, and this laboratory alone must at the present time be training more control system technologists than all the Canadian universities combined. Moreover, the emphasis at MIT, and at several other US schools of engineering, is the integration of control system technology with such allied disciplines as communication theory and manipulation of data.

CONTROL

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Rein or Spur?

BRITAIN IS NOW PROBABLY SPENDING MONEY ON guided weapon development and production to the tune of a hundred million pounds a year. We do not question the wisdom of this. History shows that prosperous powers which neglect their defences through a desire for easier living do not prosper for long. While it is doubtless true that spending too much on military security will imperil economic security and therefore be self-defeating, the partially informed layman must be chary about criticizing the sizes of the military and civilian slices of national cake; ineluctably full details of Service requirements and potential enemy activity must be denied to him.

What we do question is whether Britain is realizing the full possible civil benefits of this great military expenditure. The g.w. programme rightly ensures that numerous first-rate scientists and engineers—men who would be heaven-sent in many short-staffed laboratories of civilian industry—are caught full-time in the maw of g.w. establishments. Much of the equipment they develop may have no immediate civilian application, apart from some limited use in aircraft. But the numerous control systems for guided weapons employ techniques (e.g. hydraulic servos) and hardware of much significance for industrial control. For a highly competitive, highly automatic era lies ahead, in which closed-loop kinetic control is likely to become as important to industry as process control is at present.

Although individual firms developing g.w. equipment often obtain the Ministry of Supply's permission to declassify particular components for non-military applications, the publication of technical information about control engineering developments in g.w. laboratories is most arbitrary. The content of published g.w. reports, articles and papers seems to depend on the enthusiasm of individual authors rather than on any orderly programme of release of information. Until an intending author has submitted his manuscript and illustrations to the Ministry's technical security department and has perhaps had part of them deleted he cannot be quite sure about what he may divulge. True, he has access to broad security classifications and he may be able to arrange a talk with the Ministry's security officers before he starts work. But he cannot release details with confidence, and he probably tends to play safe, for no author likes to waste half a manuscript. Is it surprising that the published g.w. information in Britain is patchy and that there are as yet no real British textbooks on the subject? In effect the release of information is negative—no positive urge comes to publicize everything permissible.

In making this point we are not criticizing the Government security officers in their vetting of manuscripts and photographs. Within its terms of reference, the procedure for this is apparently working well and more quickly than it was a year ago. Clearly one must run no risk of compromising operational security or of giving away valuable design information to potential enemies. What is wrong, we feel, is regarding a guided missile as 'just another weapon'; g.w. development embraces too much work on swiftly advancing facets of light engineering. Besides the periodic security reviews of particular missile systems, the Government could well appoint a senior scientist to spur firms on g.w. development work to publish permissible technical information with likely civil application. Although industry's prime need, for speeding the introduction of autocontrol, is more first-class engineers rather than more technical information, a drive to publicize technical development in g.w. control would bring its economic rewards.

Not surprisingly, many people have for some time been waiting for a surge of g.w. information to be released, as was information about nuclear energy and radar at the end of the war. A full-scale convention on g.w. technology before, say, the Royal Aeronautical Society would be of direct benefit to industrial control system engineers and would be good international publicity for British achievement. The Government should examine whether they can make it possible.

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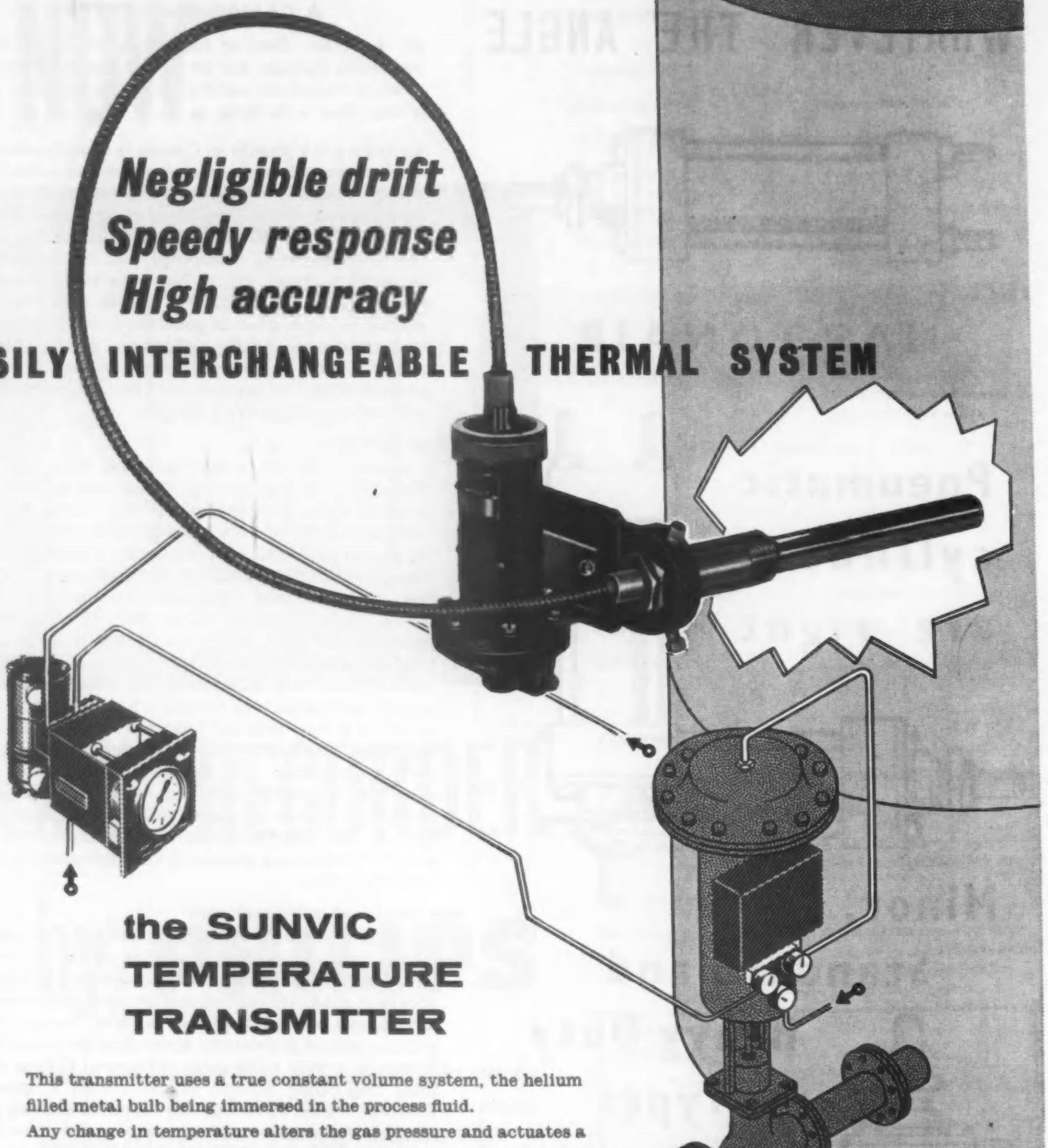

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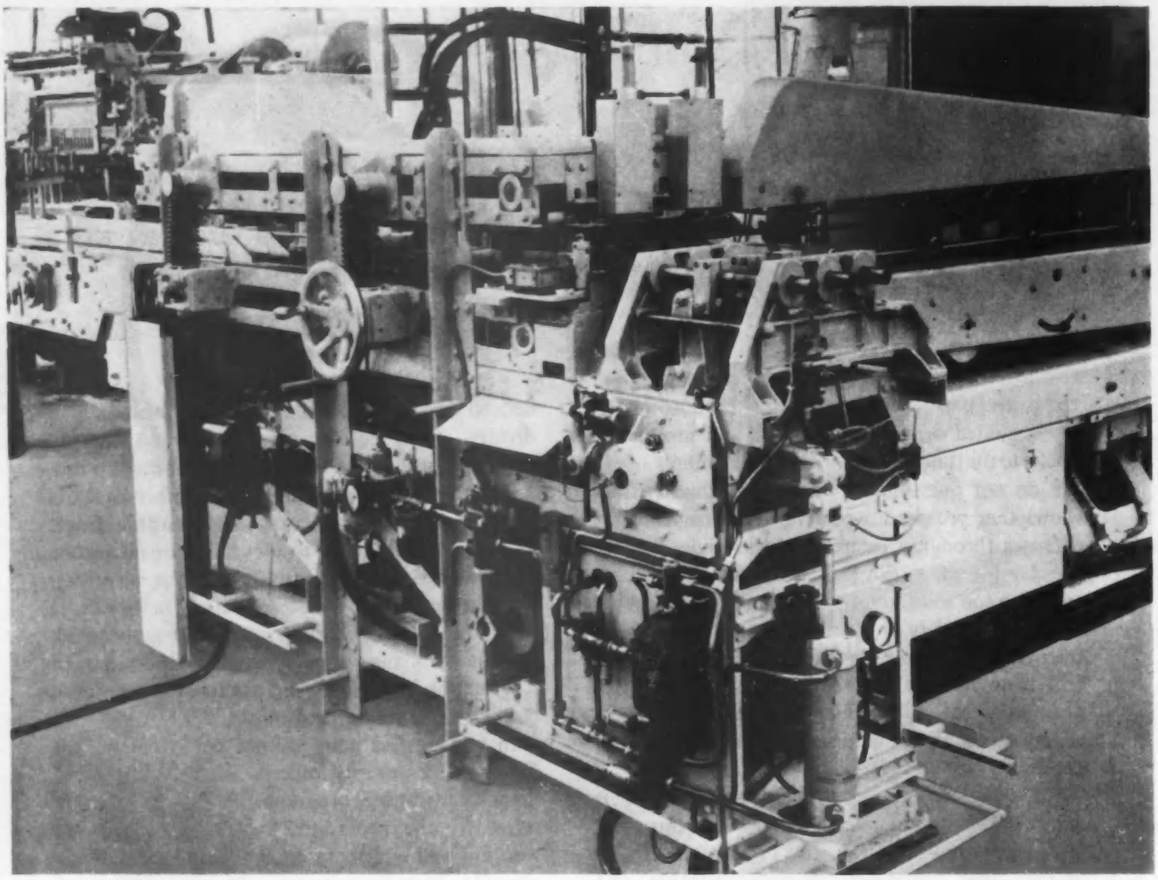

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INDUSTRY'S VIEWPOINT

A monthly article by a prominent man in the control industry on a subject chosen by himself

Solartron's Chairman and Managing Director, Mr John Bolton, says that the instrument industry and its customers must get together in design. He pleads for more . . .

PARTNERSHIP IN AUTOMATION

IN LAST DECEMBER'S ISSUE, MR JOHN FIELDEN reminded us of the competition which the British instrument industry faces in the industrial control field and warned us of the danger of falling behind. Mr Vorlander, in the January issue, stressed that, in speeding the introduction of automation, the instrument industry must be able to show its potential customers that substantial benefits are to be gained from extensions of control engineering.

I see the vital link as the need for a sense of partnership between the potential customer and the instrument designing company.

Britain sparked off the Industrial Revolution at the end of the 18th century, but the extent to which we have fallen behind in the race to put the muscle power of mechanization behind our work force is reflected in the vastly higher output per person employed in manufacturing industry in the United States (and it is no good us hiding behind the excuse that America has 'such a big home market', because, as 'Wagon Train' on ITV reminds us weekly, the task of creating that mass market was a tough one).

If we believe in the need for Britain to stay in the first flight in world trade and in standards of living, we must also recognize that we now have an opportunity to lead in automation without the burden of writing off a colossal investment in the older forms of 'mechanical' machinery.

Shall we now have the courage and the enterprise to take advantage of this position?

It seems to me that our design work is often misrepresented as being highly speculative and possible customers approach the instrument industry's new products with great doubt. Whereas, in fact, there is a close analogy with the house-designing job of the architect. Our building bricks are assemblies of relatively standard electronic and mechanical components—only very rarely need we venture into new materials. And yet we're often in the position of *persuading* a manufacturer to experiment with a new equipment. To me this is like an architect designing and building a new type of house and having to rely on persuading someone's wife to like the kitchen.

Moreover, after expending scarce design and engineering effort on a product, our margins are unlikely to compare with the annual savings the customer will achieve. *Surely here is a mutuality of financial interest.*

The user possesses the only complete knowledge of his process and we, in the instrument industry, have our complementary knowledge of the electronic and other techniques of control engineering. *Surely here is a mutuality of design interest.*

I don't believe that industrial instruments would be lying about 'out of order' (to quote CONTROL's December Leader) if the actual users—the foreman and the factory manager—had taken part in creating their design, and the users' Board of Directors had helped to sponsor the development cost.

This 'partnership in automation' is something that CONTROL *can, and I hope will, help to bring about.*

John Bolton

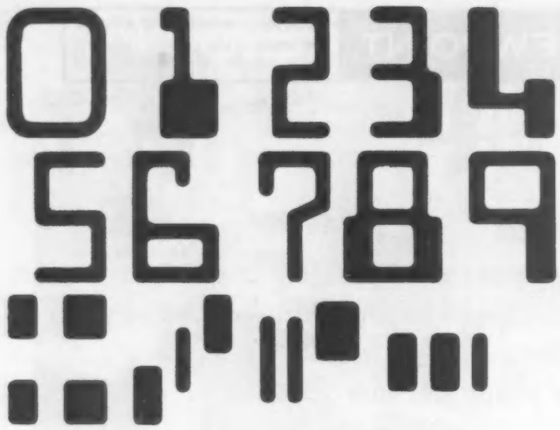

Fig. 1 The magnetic characters being used by the American Banking Association

This month the IEE is running a computer symposium, part of which covers character recognition. Here is a simple review of UK and USA reading machines now in production. Watch them for possible application to your data-processing system or to machine tool control

READING BY MACHINE

by **P. A. M. CURRY**
Solartron Electronic Business Machines

MUCH THOUGHT AND EFFORT HAVE GONE INTO THE development of printed character recognition devices during the past ten years. Now practical machines are beginning to operate in the field. This interest in printed character reading has, of course, arisen with the rapid spread of machines in the office. Often the cost of manually converting business data for processing by punched card equipment or computers has been substantial, because of the volume involved. In addition manual conversion takes much time and can introduce inaccuracies. Thus there has been a considerable urge to develop some means of automatic conversion of data from the printed form to machine language.

What will a machine recognize?

Several factors affect the design of character recognition machines and some of these are interrelated. The most important is probably the style and quality of the characters. The manufacturer must decide initially whether his equipment is to recognize conventional arabic characters or only characters printed in a special type face; and whether it will handle poor-quality characters produced by a simple printing mechanism or only high-quality characters printed by expensive equipment.

Related to these two decisions are of course the accuracy of the mechanism and the cost. If the data are being converted for accounting purposes a high accuracy system must be adopted, for otherwise the problem of locating errors becomes acute. Again by adopting high-quality stylized characters, high accuracies can be obtained more cheaply than by a machine designed to read normal poor quality characters, as produced on an office typewriter. However, in sorting documents, one can normally accept lower standards of accuracy, because a relatively economic check is feasible subsequently; the cost is much more important, because of the physical limitations in paper handling speeds. These limitations necessitate each installation having a number of sorting machines, in which the actual character recognition may be necessary for only as little as one-hundredth of the document handling cycle.

Also important for the design of character recognition machines are the speed required, the amount of mutilation expected, the format, layout and quality of the documents and the output required. In reading the descriptions below of practical methods one can see which factors have been considered important in particular machines and the effect of these on design.

Magnetic and optical recognition

Most systems of character recognition are based on dividing the character up into a number of successive lines or areas in which a decision is made as to the amount of black or white. This information is then passed to a processing unit designed to recognize and discriminate between different characters.

Probably the two major systems which have been developed to date are (i) magnetic and (ii) optical. In the magnetic system the document, with characters printed in magnetic ink, is passed under a reading head, which is a narrow gap in a magnetic circuit. The variations in the magnetic circuit are then measured electrically and the information processed to enable the characters to be

recognized. The scanning motion in one direction is provided by the movement of the paper, and in the other direction the average intensity of the characters in each vertical line is measured.

Optical character recognition is, however, based on scanning each character with a flying spot of light which may be generated on the face of a cathode ray tube or moved by an optical system. Since the character is scanned with a spot rather than a long gap, one can discriminate between areas of black and white within each vertical line into which the character is divided. This approach appears to offer a much higher effective resolution, for with variations in intensity of printing, the positional significance of black and white in the vertical direction is of considerably more value than a summation of the intensity within each vertical column. The use of this positional significance in the vertical direction does, of course, put added importance on the need for a system which will take up misregistration in the vertical plane.

Several organisations are working on both magnetic and optical methods. However, in Britain and the USA there are three machines known to be in production. These are the magnetic reader manufactured by General Electric* in the USA; an optical reader manufactured by Intelligent Machines Research Corporation in the USA; and an optical reader being manufactured by Solartron in England.

GE's magnetic reader

The magnetic reader (*1*) was developed to read ten digits and four special symbols printed in magnetic ink

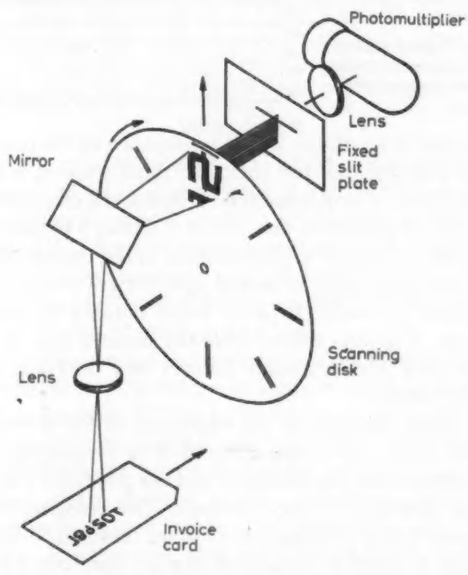

Fig. 2 Simplified view of the IMR scanner

(Fig. 1), at the rate of 1200 per second. The printed characters are first magnetized to saturation by a write magnet to erase any previous magnetic history. They then pass under the reading head, the width of which is small in comparison with the line width of the characters. The character generates a voltage waveform which is amplified and then fed to a delay line. The stored waveform is sampled at a number of points along the delay line, each sample point going to fourteen resistor matrix boards, one for each parallel channel representing a character.

* This machine was developed by the Stanford Research Institute.

The resistor matrix for a given character in essence stores the waveform for that character, so that there are fourteen stored waveforms to compare against the particular waveform in the delay line which represents the character being read. The comparison output appears in each of the fourteen channels. By means of suitable summary amplifiers and a peak comparator circuit the correct output line is selected.

Fig. 3 IMR self-check characters

IMR optical reader

The IMR optical reader (*2*) was initially designed to read conventionally printed numerals. The document to be read is moved past a reading station, and an image of the information on the document is focused onto a scanning disk containing 20–40 radial slits, each 0·010 in. wide (Fig. 2). This disk is made to rotate at 10,000–15,000 rev/min. Immediately behind the rotating disk is a fixed plate containing a slit 0·010 in. wide. As the document is moved horizontally past the reading station, an image of the information on it moves across the system of intersecting slits. More than twenty vertical scans are made to cross the character, with adjacent scans overlapping slightly.

The light signals from the reading station are focused onto a photomultiplier, where they are converted into electrical signals whose amplitude is always proportioned to the intensity of the spot of light. The photomultiplier output is then fed to a video channel, in which it is amplified and clipped at voltage levels (+ 15V and − 25V) used in subsequent logical units. Also developed in the video channel is a feedback voltage which holds the amplitude of the 'black pulse' constant, compensating for variation in document reflectivity and photomultiplier sensitivity.

Signals from the scanner are analysed by a small,

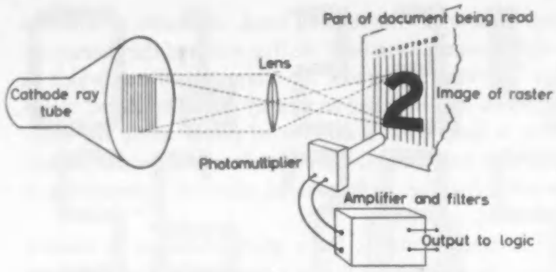

Fig. 4 How the scanner used in ERA operates

special purpose computer called an *interpreter*. Analysis of the signals resulting from the scan of a whole character yields information from which the identity of the digit may be determined. The interpreter consists of AND gates, OR gates, inverters, pulse amplifiers, pulse width measuring circuits, staircase counters, reset generators and a special purpose circuit called a *vertical locator*.

The type style being adopted in some systems using IMR readers is shown in Fig. 3. Recognition of these characters is carried out by determining which combina-

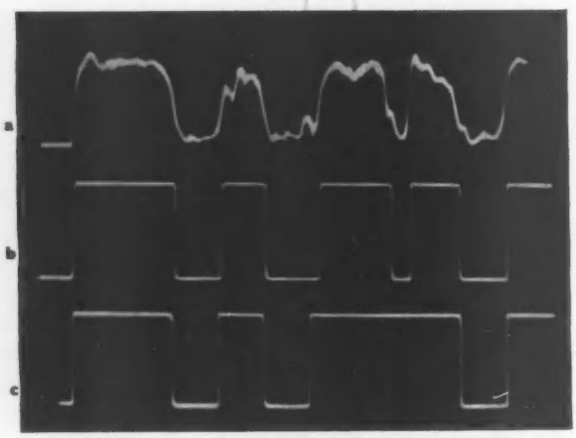

Fig. 5 Oscillograms showing effect of clipping and pulse width discrimination

a A typical variation in light intensity obtained along one line of the raster
b The same waveform after clipping and amplifying
c The waveform of **b** after pulse width discrimination

tion of the following seven strokes is present: short vertical upper left, short vertical upper right, short vertical lower left, short vertical lower right, horizontal top, horizontal middle, and horizontal bottom.

Solartron's ERA

The Solartron ERA (Electronic Reading Automaton) has been designed to accept moderate quality impressions and to recognize these at a speed of approximately 250 characters per second with extremely high accuracy. It can also be programmed for almost any type face and therefore does not require special printing.

The character to be read is scanned along sixteen vertical lines using a flying spot scanner, the image of the raster being focused onto the character by means of a lens (Fig. 4). As the spot traces out the raster, the reflected light signal from the paper is picked up by a photomultiplier.

A typical signal for one line of the raster is shown in Fig. 5a. The irregular waveform arises from mutilation and dirt around the character. By clipping the signal at a predetermined level a sharp white/black boundary is obtained for each character (Fig. 5b). This process is automatic and the actual level is varied according to the quality of each character. Pulse width discrimination is also used to remove information obtained from dark spots near the character; Fig. 5c shows the resulting waveform.

In practice the raster is small compared with the tube face. By moving the raster, characters can be read along a line without moving the document sideways. This

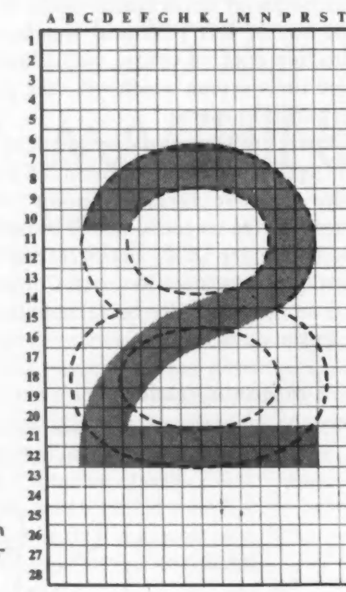

Fig. 6 Typical position of characters in recognition store of ERA

advantage of a cathode ray tube, coupled with the control of the scanned area for character misalignment, allows the machine to search for and recognize the character in a very short period (in fact, about 1/250 sec.) In order to allow for considerable misalignment in the vertical plane each line of the raster is broken up into twenty-eight bits, the height of each character being covered by about fourteen. The information from the scanned area is fed sequentially into two parallel stores, one for black and one for white.

A typical position of two characters in the store can be seen from Fig. 6. The columns A to T represent the scan lines across the character and the positions 1 to 28 storage elements in each column. The recognition is achieved by combining the storage element outputs through a series of AND/OR logical decisions which enable us to make maximum use of the significant information available. To illustrate this, differentiation between the characters 2 and 8 can be obtained by the areas D 13 and R 18. When both these areas are black plus certain other conditions a decision for 8 would be obtained, while the converse condition of these storage

elements plus similar conditions would produce a recognition signal for 2.

The AND statements are used to define characters which are free from imperfections. However, referring again to Fig. 6, the cells D 13 and R 18 can be backed up by other appropriate logic to overcome a smudged 2 or a mutilated 8. The OR statements give additional flexibility. For instance, instead of just requiring the areas D 13 and R 18 to be black for 8 and white for 2, the statement can be 'D 12 or D 13 or E 13 or E 14 and R 18 or R 17 or P 16 or P 17 must be black for 8 and white for 2'. This allows for a certain amount of mutilation, smudging and misalignment. By selecting suitable logical connexions of appropriate areas it is possible to recognize one figure from any other. If the signal obtained does not conform with any character the machine signals a reject. It should be stressed that the logic is not forced to make a decision. The actual procedure for a reject will, to a certain extent, depend on the output mechanism being used. However, when a reject occurs, the output from the reader is used to take appropriate action.

Identification of a character is signalled out by a pulse on a wire, there being one wire corresponding to each character. This signal can be used to operate a card punch, tape punch, sorter, magnetic tape unit or fed to a computer through suitable linking circuits.

Applications of the American machines

The General Electric magnetic reader is being used to read the information printed in one straight line along the bottom of cheques, as shown in Fig. 7. The data printed will be the American Banking Association

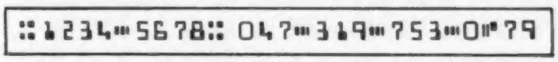

Fig. 7 This strip of information is printed at the foot of ABA cheques, for automatic reading by the GE magnetic recognition machine

number, routing symbol, etc. which are preprinted on cheques by letterpress or photo-litho. The amount, and sometimes the account number and transaction code, are printed on after the cheques have been paid in at a bank. A number of firms are engaged in developing suitable magnetic transfer ribbons and encoders for this purpose, as the quality of print must be high.

The cheques are fed past the reading head at the rate of 750 per minute and the information read is transferred to a computer for up-dating customer accounts. The cheques are then sorted into appropriate stacking bins.

The IMR equipment described is being used to process petrol credit invoices. Credit cards have the account number embossed in the appropriate type style. When petrol is purchased, this account number is imprinted onto a punched card invoice form and the amount is written. These cards are then fed past the reading head at 180 cards per minute and have the account number automatically punched. The amount is punched into the cards by a combination of an adding machine and card punch intercoupler as the by-product of a proofing operation.

The customer's account number contains a redundant digit which makes the account number self-checking according to the IBM scheme. By this means, if one and only one character has been rejected at the end of the reading field, this character can be calculated and inserted in the empty storage position.

Other applications of the IMR reader are the automatic processing of utility company billing stubs prepared on tabulating machines, the reading of travellers' cheque serial numbers and the processing of invoices for *Readers Digest*.

Applications of ERA

The first production model of the Solartron ERA is reading the characters 0–11, a plus sign and eight letters of the alphabet, selected for the particular application. It is to be used by Boots Pure Drug Co to read cash register rolls similar to the one shown in Fig. 8. These

```
B                   S
B H   1 1   1 1
B H   2 2   2 2
B H   3 3   3 3
B X     4   4 4 ½
B X     5 1 5 5
B O     6   6 6
B O     7   7 7
B O     8   8 8
B O     9   9 9
B X           11
B X           10
B
B   1 0 8   0 6 ½ S
B H   1 1   1 1
B H   2 2   2 2
B H   3 3   3 3
B X     4   4 4 ½
B X     5 1 5 5
B X     6   6 6
B O     7   7 7
B O     8   8 8
B O     9   9 9
D H           10
D H           11
B
B   1 0 7 1 8 9 ½ S
B
T                   S
```

Fig. 8 An example of a detail roll used by Boots in their retail branches. Such rolls will be read automatically in the firm's headquarters at Nottingham, where the first practical installation of ERA is now nearing completion

rolls will be fed to the reader by means of a mechanical handling device which will automatically rewind the paper after it has passed the reading head. The information will be fed direct to a computer which will accumulate totals by the shop assistant code in Column 1 and the category of item in Column 2. This will enable the organization to calculate a cash total for all their shop assistants and to obtain a sales analysis. Such an analysis would be completely uneconomic if this information had to be prepared on punched cards. Clearly one alternative would be to have tape punches attached to each cash register. However, since large chain stores use well over a thousand registers, the additional capital cost involved is very much greater than the cost of one central reading machine to do the work.

Various retail cooperative stores are planning to install ERA to read cash register rolls produced at all their branches. On the roll will be printed the customer's

number and the amount for each sales transaction. ERA will operate a battery of card punches and the information for each transaction will be punched onto cards which can then be sorted by customer's number and tabulated in order to calculate the dividend for each customer. A similar application is to be used in order to obtain an analysis of sales of shoes and women's dresses. Each time a sales transaction is keyed on a cash register the code number of the particular item sold (signifying size, colour, style etc) is recorded. This information is later read by ERA at a central location and processed by a computer or punched card installation. This up-to-date information will greatly assist merchandizing, stock control and production planning. Moreover cheap portable printing machines will probably be used by door to door salesmen in many industries and by electricity and gas meter readers, to produce a detail roll recording information for each transaction which can be processed quickly and economically, to obtain a sales analysis, delivery and production programmes and utility bills.

One other important application of ERA is in traffic control analysis. The introduction of machines which print tickets at the point of issue for transport organizations offers the opportunity to provide source information for much more effective analyses than have hitherto been possible. This is a field where capital investment is very high and greater utilization can yield appreciable economies. Each time a ticket is printed, the relevant part of the information for analysis purposes is duplicated on an audit roll within the ticket issuing machine. Periodically these audit rolls can be sent to a central point where the information can be analysed for accounting purposes, and for getting a better estimate of train and bus loadings.

Future developments

The machines described above are now well into production. There are, of course, many other techniques and applications under development at the present time. One which was announced recently is the figure reading electronic device (FRED) being developed by EMI Electronics. This system divides the character into five vertical columns and decides whether each is mainly white or black. As the right hand edge of each character is always black, the code gives a maximum of sixteen possible combinations. This system requires a special type style and good quality print. Other interesting projects are the reading of hand-written characters, the reading of the complete alphabet etc.

There is a great demand for a means of reading characters which are handwritten even though this may call for a highly stylized form of writing. Stylized forms of writing, however, can prove expensive in that they slow down the work of the writer in order to obtain a character that a machine can recognize. In trying to solve this problem T. L. Dimond of Bell Telephone Laboratories (*3*) has arrived at a logic which places fairly wide limits on the writer, and at the same time produces a character capable of machine recognition. It is quite possible that further developments will be seen in this field in the next year or two.

The reading of the complete alphabet has many other applications—in insurance, postal sorting, machine translation, just to name a few. Development in this field is well under way in the United States, and is being sponsored by the Federal Government through defence agencies and the Post Office Department. A machine is being developed for one of the defence agencies which will read the complete alphabet, upper and lower case in one type style. It is hoped that should this prove successful, contracts will be placed for developing machines to read foreign alphabets. These readers will be used to feed information to computers working on translation of information. The reading will probably be of technical articles, and while the whole process will not be completely automatic such a reader could considerably reduce the manual punching required.

The United States Post Office (*4*) has received encouraging progress reports from research on automatic sorting of letters. In a trial run, letters with typed addresses were sorted by eighteen major cities or states successfully. Because of the fact that the type styles from envelope to envelope vary, the machine recognizes only enough information to identify cities and states, and does not completely identify each character by itself. The envelope speed during the reading operation is 30 in/sec.

Handling documents

Closely associated with character recognition is document handling. As the speeds of character reading increase it becomes imperative to be able to feed separate pieces of paper past a reading head at higher speeds. Considerable development is being carried out by specialists in the field of paper handling. While documents have been handled at rates up to 3000 per minute (*5*) under laboratory conditions, speeds of 750 per minute are being achieved most satisfactorily with production machines. These machines are handling mixed sizes from a minimum of $2\frac{1}{2} \times 5\frac{1}{4}$ in. to a maximum of 4×10 in. and variation in paper from good-quality printing to card stock. With further development greater speeds will certainly be attainable.

Summing-up

Considerable progress has now been made in automatic character recognition. With actual machines being delivered it will soon become an essential feature of many data processing systems. Of course, many problems are still to be solved, and the speed of doing this will depend to a large extent on the speed at which industry is willing to invest in this field.

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An experienced instrument engineer reviews the principal methods used in automatic inspection of thickness and material

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Measurements Division, Tube Investments Technological Centre

Replacing the human inspector—2

IF A CONDUCTING MATERIAL IS WITHIN THE MAGNETIC FIELD of a coil carrying alternating current, electric currents are induced in the metal. To the designer of electrical equipment these eddy currents are generally undesirable. However, the effect is put to advantage in induction heating and in some methods of non-destructive testing. The use in non-destructive testing depends on the effect on the impedance of the coil of the eddy currents. I am concerned here with the use of this effect for dimensional measurement; its use for detecting flaws in materials is discussed in a later section.

In Fig. 8 is shown an eddy current method of gauging the thickness of conducting sheet material. The effect of the induced currents in the sheet is to reduce the magnetic field due to coil A in the region of coil B. The attenuation depends on the frequency and on the conductivity and thickness of the sheet. If the conductivity does not vary, the voltage induced in coil B is a measure of the thickness of the material. The choice of frequency is not critical but it should be approximately equal to

$$\frac{25\zeta}{\mu t^2} \times 10^6$$

where ζ = the specific resistance, ohm–cm;

μ = permeability, c.g.s. units; and

t = thickness, cm.

A separate detector coil is not essential to this method of measurement because the induced currents also affect the electrical impedance of coil A. Again, if the frequency is constant thickness and conductivity both affect the indication: if conductivity remains constant, the thickness can be measured from one side. This is used for measuring the thickness of thin coatings on insulating materials.

If a cylindrical rod or tube is placed inside a circular

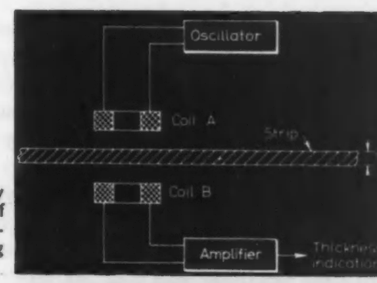

Fig. 8 An eddy current method of gauging the thickness of conducting sheet material

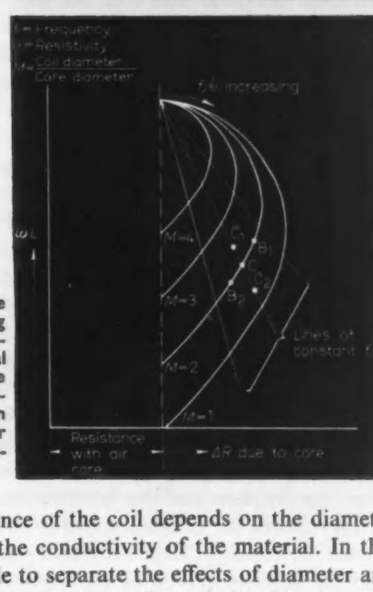

Fig. 9 Impedance diagram for a long solenoid with a non-magnetic cylindrical core showing the method of discriminating between changes of diameter and changes of conductivity

coil, the impedance of the coil depends on the diameter of the rod and the conductivity of the material. In this case it is possible to separate the effects of diameter and conductivity. Fig. 9 shows the relationship between the impedance of the coil and the frequency, conductivity and diameter of the rod. Suppose that with a certain rod inserted in the coil the impedance is represented by the

point C, then a change of diameter will move the impedance along the line C_1CC_2 while a change of conductivity of the metal will cause the working point to move along the line B_1CB_2. Thus small changes from the two causes can be distinguished by observing the phase of the impedance change. This effect is used both in the measurement of diameter and in the measurement of electrical conductivity. In each case the circuits are designed to reject by phase discrimination the effect of the variable which it is desired to ignore.

In practice these eddy current methods are suitable for non-ferrous materials. They can be used for ferromagnetic materials also, but local variations in magnetic permeability render them inaccurate.

Ultrasonics

Sound waves travel through solids with a velocity which depends on the density and elastic properties of the material. If the velocity is known, the time of transit of a sound wave through a specimen is a measure of the distance travelled and thus of a dimension, say the thickness, of the part. The thickness of a parallel-sided section can be determined from one side comparatively easily because sound waves are reflected at the remote surface. The transit time is twice the thickness divided by the velocity. In practice the velocity of propagation is seldom known with sufficient accuracy for a direct measurement of thickness to be made and the usual practice is to calibrate by comparison with a test piece of known thickness.

The sound waves are generated by means of piezoelectric crystals; quartz and barium titanate being the most usual materials. A film of liquid, oil or water, between the transducer and the part provides acoustic coupling between them. One common way of determining thickness is to measure the time of transit of a short burst or pulse of vibrations; a more accurate method is to find the resonant frequency of the thickness mode of vibration of the section to be gauged (*4*).

For the pulse method the frequency of the vibrations is not critical but it is preferable to use the highest frequency which can be transmitted without troublesome attenuation; in metals frequencies of the order of 1 Mc/s are commonly used. The repetition rate of the pulses is usually between 50 c/s and 1000 c/s. Each pulse of vibration is reflected at the two surfaces of the part, and because of the low attenuation makes many transits of the thickness before its amplitude becomes too small to be detected. The transducer used to excite the vibrations is also used to detect the pulse each time it is reflected at the transmitting point; the transit time is determined from the frequency of the reflected pulses. This method is not suitable for gauging very thin sections because the transit time must be large compared with the pulse length and the latter is limited by the highest frequency which can be transmitted without troublesome attenuation; in practice the minimum thickness in most metals is about 0·2 in.

In the resonance method the transducer is again used both to excite and detect the vibrations. The transducer is driven by an oscillator whose frequency is swept automatically through a narrow band containing a suitable harmonic of the resonant frequency of the section. When resonance occurs the amplitude of the vibration increases sharply and the power drawn from the driving circuit increases. The thickness is then

$$\frac{Vn}{2f}$$

where

V = the velocity of propagation.
f = the resonant frequency.
n = an integer depending on the harmonic used.

This method is suitable for gauging sections in the range 0·005 in. to several inches. It is more difficult to set up because the frequency sweep usually embraces more than one harmonic and the multiple indications which result are confusing.

Both these methods require the surfaces to be parallel and to have a reasonably smooth finish. However, the surfaces need not be flat and the thickness of a tube wall can be measured. The material must be free from porosity and flaws. The accuracy which can be obtained depends on the smoothness of the surfaces and on the consistency of the velocity of propagation; typical figures for flat surfaces are 1-2% for the pulse method and 0·2-0·5% for the resonant method.

Manually-operated ultrasonic thickness measuring equipment is used extensively for gauging simple regular sections such as sheet, plate and tubing. The main difficulty in automatic measurement lies in maintaining satisfactory coupling between the transducer and the part. This difficulty can be overcome with a suitable surface finish and care in mounting the transducer and supplying coupling fluid. Some additional complication of the instrument is necessary but since the output is in electrical form in the manual instruments no basic difficulties arise. The method has the advantage of being suitable for thickness measurement from one side only.

Penetrating radiation

Beta rays, gamma rays, and X-rays are attenuated by matter by an amount which depends on the distance travelled, and the density of the material and the nature and energy of the radiation. This phenomenon forms the physical basis of a further method of thickness measurement.

The basic arrangement simply involves placing the material to be gauged between a source of radiation and a suitable detector. The amount of radiation reaching the detector is a measure of the mass per unit area of the material, provided the intensity of radiation from the source is known. For material of known density, mass per unit area can be translated into thickness; calibration is usually done by means of test pieces so that it is not necessary to know the source intensity in absolute terms provided that it is sufficiently constant.

The use of such radiations involves the possibility of

danger to the health of personnel working near by. The recommended maximum radiation intensity near to the instrument and maximum radiation doses for personnel are set out in Draft Factory Regulations (*5*). Provided these rules are strictly obeyed consideration of health risk need not influence the choice of this type of instrument. The radiation will not cause the material gauged to become radioactive and the intensity is not sufficient for the radiation to affect its properties.

The advantageous feature of this method is that the attenuation caused by air is almost always small compared with that caused by the material to be gauged and thus the part can be separated from the radiation source and detector by an air-gap. This makes it feasible to gauge material which is very hot, easily damaged by contact, or travelling at high speed (*6*).

Errors in measurement

The generation and attenuation of the penetrating rays depends on processes which are of a random nature and as a result thickness measurements using these effects are subject to errors which can only be predicted in statistical terms. Thus, in order to make an accurate measurement it is necessary to determine the average intensity at the detector over a period of time. The relation between accuracy and time depends on the method of averaging and the intensity of radiation; it can be summarized as follows. If the same equipment is used to measure the thickness of the same piece of material many times, the average reading will, subject to calibration errors, approach the true value as the number of measurements increases. The probability of a single reading having a given error can be expressed in terms of σ, the r.m.s. value of the errors, thus:

x	PROPORTION OF READINGS HAVING AN ERROR NOT EXCEEDING x,%
$0{\cdot}67\sigma$	50
σ	68
2σ	95·4
3σ	99·7

Each measurement is itself an average reading of intensity; if this average is obtained simply by integrating with respect to time over a period T then

$$\sigma = \frac{100}{\alpha\sqrt{nT}}\ \%$$

where n = the average number of quanta detected per second and

α = the % change of n due to a 1% change of thickness.

If, as is more common, the averaging is effected by converting each quantum into a definite quantity of electricity, and feeding the resulting current to a resistance capacitance integrating circuit then

$$\sigma = \frac{100}{\alpha\sqrt{2nRC}}\ \%$$

where RC = the integrator time-constant.

In many practical instruments the intensity at the detector is limited by the size of the source allowed by safety considerations or by the performance of the detector, and the fluctuations of source activity can cause significant errors. Errors due to this cause and the response time of the instrument are related by the expressions for σ given above.

Detectors are either ionization chambers or scintillation counters. The main limitation of the former is in drift of characteristics due principally to changes in temperature; to reduce trouble due to this cause two ionization chambers are sometimes used in a balanced circuit. The scintillation counter does not suffer from drift but the maximum counting rate is limited, usually to about 100,000 counts/sec. (If n = 100,000, $\alpha = R1$, and $RC = 1$, then $\sigma = 0{\cdot}22\%$.)

The principal applications of this method of gauging have been in the thickness measurement of material which is made in sheet or strip in a continuous process, i.e. in such processes as paper making and the rolling of metal sheet and foil (Fig. 10). The gauge is used either to indicate the thickness or to control the process; thus in strip rolling the signals from the gauge may be used to operate the screwdown control on the rolling mill.

Gamma ray gauges have also been used for measuring the wall thickness of metal tubing by inserting the radioactive source inside the tube and placing the detector on the outside. This technique is limited to measurement near to the end of the tube. An alternative method in which both the source and the detector are outside the tube has been proposed: in it the radiation reflected from the material is a measure of the thickness of the wall thickness. This reflexion type of gauge has been used for gauging steel strip in applications where the transmission type could not be used for reasons of accessibility. It is more difficult to achieve a given accuracy than with transmission gauging because great care must be taken to shield the detector from direct radiation from the source, and the relationship between thickness and reflected radiation is very sensitive to the distance between the surface and the measuring gear.

Gauges for a wide range of metal thickness are available, from beta ray gauges for aluminium foils as thin as 0·0002 in. to gamma ray gauges for steel up to 2 or 3 in. thick.

The accuracy of these instruments is generally of the order of 0·1–1%. They are usually provided with automatic self-standardizing facilities to compensate for drifts due to temperature changes; the principal sources of error are the random variations of source activity and changes in the relationship between attenuation or reflexion and thickness, for example due to mechanical displacement of the strip and changes in density of the material. Typical values of response time in practice are 0·1 sec for beta ray gauges and 0·5–1 sec for gamma ray gauges.

MATERIAL QUALITY

The main parameters with which we are concerned in assessing material quality are the chemical and physical state of the material, the surface finish and the presence

of mechanical flaws at or beneath the surface. Usually the bulk properties of the material do not vary rapidly between parts made from the same batch of material and thus sampling methods which do not justify automatic equipment can be used. In general, therefore, the most common and important problems in inspection for material quality are concerned with flaw detection. Finding and measuring subsurface flaws in opaque materials must depend on the use of some form of instrument. The human eye is a very powerful means of scanning a surface for blemishes and cracks but it is unable to make any but the roughest estimate of the size or severity of a surface fault, and the depth of a crack can be determined only by the use of an instrument.

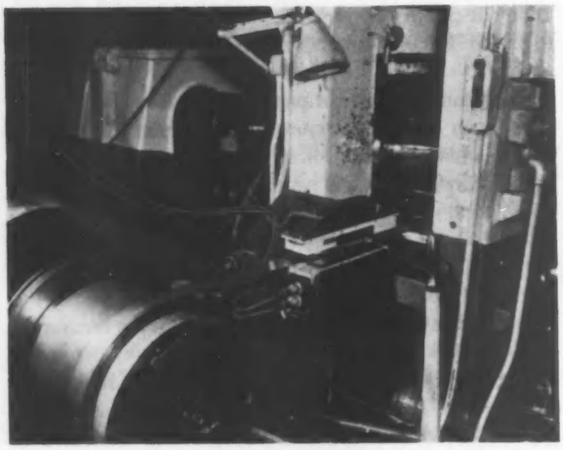

Fig. 10 A beta ray thickness gauge in use on a sheet rolling mill (*courtesy Baldwin Instrument Co Ltd*)

A great deal of work has been done on the development of methods of finding and assessing subsurface flaws and surface cracks which are too fine to be readily detected by visual methods. In surface inspection for blemishes which can be detected by the eye, visual inspection is unchallenged because of its great speed and flexibility. As a result there is no proved method of automatic inspection of surfaces for flaws.

Gamma and X-rays

Radiography is the longest established method of detecting subsurface flaws and it is still the most widely used. Because the wavelength of the energy transmission is much shorter than in any other method of flaw detection, it is the only method by which the size of small flaws can be determined with any degree of confidence. However, no satisfactory automatic method of using these unique properties has been devised.

Optical methods

Apart from the very limited field of transparent materials the use of visible light is necessarily restricted to surface inspection. Hand-operated instruments are used for spot measurements of surface finish and colour; in these a photoelectric cell is the means of measuring light intensity. Such instruments could be readily converted to automatic operation because the indication is by electric meter.

There is a need for an instrument for the 100% inspection of tinplate for surface blemishes while the strip is travelling at high speed. High speed scanning by means of a beam of light and rotating mirrors with measurement of reflected light from the surface by photoelectric cells is the most promising method. Instruments based on this principle are under development in this country and the USA. That it is found necessary to use such elaborate methods is a good indication of the difficulty of the problem of devising satisfactory alternatives to visual examination.

Ultrasonics

In addition to their use for thickness measurement high frequency sound waves ($\frac{1}{4}$ to 25 Mc/s) are a powerful means of obtaining information about the properties of material beneath the surface. This is because the propagation of sound is affected by the elastic properties and the density of the material. This is used in research as a means of determining the elasticity and mechanical damping capacity of materials, but measurements of this kind have not been used for routine inspection. However, at a boundary where the acoustic properties change, reflexion and scattering of the sound waves takes place. If the size of the discontinuity is small compared with the wavelength of the sound, then its effect will, from a practical viewpoint, be negligible; only those discontinuities which approach the wavelength in sizes have a significant effect. The practical importance of this property is that cracks, blowholes and porosity can be detected by their effect on the transmission of sound waves while, if the wavelength is suitably chosen, the grain structure of most metals (some cast structures are exceptions) has negligible effect.

There are a number of different ways of using the effect of discontinuities on sound waves. The most powerful and most widely used method is to send into the material short pulses of high frequency sound waves with a repetition rate of 50–1000/sec and to detect flaws by observing the reflected energy; separate transducers may be used for transmitting and receiving or the two functions may be combined in one (*7*). An alternative method is to detect the flaws by observing the change in the strength of the sound energy transmitted through the material: in this case continuous waves are often used instead of pulses.

In the pulse method the time delay between the transmitted and reflected pulses is a measure of the depth of the cause of the echo. It is thus possible to avoid confusion between signals due to flaws and those due to the near and far surfaces of the material.

Piezo-electric transducers are used to convert electrical energy to mechanical vibrations, and as electrical detectors of sound waves. Quartz, barium titanate and lithium sulphate are the most commonly used crystals.

Ultrasonic inspection can be performed by automatically scanning the probe over the surface of the material

and providing automatic alarm circuits which are operated when the signal due to a flaw exceeds a preset magnitude. In practice one of the main difficulties is in maintaining satisfactory coupling between the probe and the work. Variation in coupling efficiency causes variation in sensitivity and must therefore be kept to a

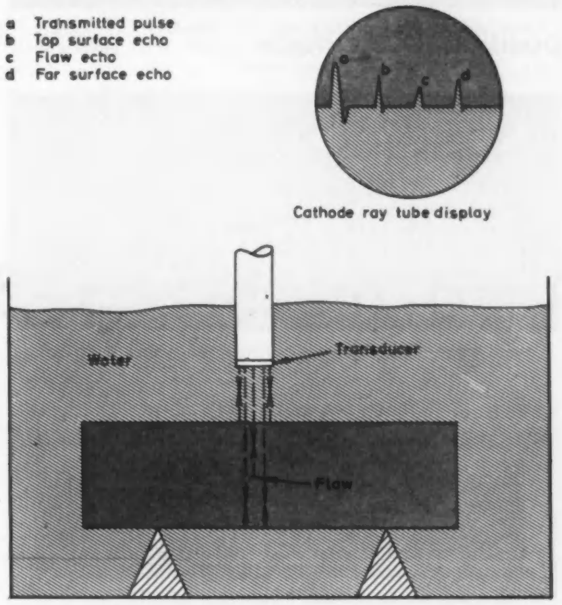

Fig. 11 The immersion method of ultrasonic flaw detection

minimum. In order to obtain reasonably efficient coupling it is necessary to have a layer of liquid or grease between the probe and the work, but even with this the coupling is variable because it depends on contact pressure, film thickness, surface finish and accuracy of alignment. One of the most effective ways of reducing trouble due to this is to have a gap of the order of inches between the probe and the work and to fill this gap with a liquid, usually water. The simplest way of obtaining this water-filled gap is to immerse both the work and the probe in water, but where this is not practicable a small tank containing the probe and sealed on one side by the surface of the work can be used (Fig. 11).

In many applications it would be uneconomic to scrap all material in which a flaw had been detected. It is therefore desirable to determine the size of flaws, a much more difficult problem than that of simply detecting them. It is generally true that in the case of the pulse echo method the amplitude of the reflected pulse at the receiver probe increases with the size of the flaw. The relationship between the amplitude of the electrical signal which represents the reflected pulse and the flaw size is complicated by a number of other factors, in particular the coupling between the work and the probes and the shape and orientation of the flaw. No general solution to this problem has been found and it is common practice to specify limits of acceptable flaw size in terms of the echo amplitude from artificial flaws, usually flat-bottomed drilled holes. When automatic ultrasonic flaw detection equipment is used it is normal either to limit its employment to detection of flaws in the literal sense, and to operate the instrument by hand in order to estimate the size of the flaws which are located automatically, or to reject all material containing detectable flaws.

Most installations of automatic ultrasonic equipment are in the form of separate testing stations which are not integrated into a production line. The aircraft industries of the world are large users of such equipment; the main application is to the examination of large pieces of aluminium and major forgings, e.g. turbine disks, prior to machining operations. The purpose is both to ensure that faulty material does not find its way into aircraft, and to avoid expensive machining operations on material which will be subsequently rejected because previously hidden flaws are uncovered during manufacture. Immersion methods are favoured for this application—the piece of aluminium is placed in a tank of water and an automatic feed mechanism carries a transmit/receive probe over the entire surface (Fig. 12). A record is made of the points where flaws are detected and subsequently an inspector uses the instrument under manual control to estimate the size of each flaw. A typical specification will call for the rejection of material containing a flaw which gives an echo equal to or greater

Fig. 12 The tank and probe traversing equipment for immersed ultrasonic testing
(*courtesy Kelvin & Hughes (Industrial) Ltd*)

than that from a $\frac{3}{64}$ in. diameter flat-bottomed hole at the same distance from the surface.

An example of the use of ultrasonic testing on a production process is found in the manufacture of resistance welded steel tube. The purpose is to detect faulty welds in order to cause automatic rejection of the faulty tubing, and to give early warning of incorrect operation of the weldmill. The probe is mounted on the mill at a point between the welding head and the cut-off. Contact and immersion methods have been used with success; in the latter the tube is threaded through a tank which has sealing gaskets to accept the tube. Some loss of water occurs but it is readily made up.

To be concluded next month

The method of position control described here has a wide field of application, from relatively crude machines to those requiring the highest possible positional accuracy

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Programmed machining—3

3. DISCONTINUOUS POSITION CONTROL

In discontinuous position control, as has been stated earlier, the motions of the machine are controlled to move from one accurate position to another, the path taken between the desired positions being indeterminate. The field covered by such position control is large. It embraces the large machines for drilling girders, boiler plates and so on, where no great accuracy is required; at the other end of the scale there are the jig boring and drilling applications, where the highest positional accuracy is desirable.

3.1 Large machines

In the larger machines analogue techniques similar to those used in the contour control system are used. There is no interpolator and one store only for each motion. The positional information is read from the tape. The store sets up the corresponding voltage and this is compared with the feedback from the position analogue unit. The motion is then driven until the error voltage is zero.

The extended analogue feature is extremely useful for these large machines. The extended position analogue unit can be driven from a rack extending the length of the machine. A rack has the property of being able to be made in sections with no discontinuity in the drive at the junction points; thus no cumulative error greater than that of one section is present. Hence the measuring accuracy of a 100 in. range of one or two thousandths of an inch can be obtained over many tens of feet of motion.

The servo is usually not the continuous type but a switch-off-at-coincidence system. In this system the motion continues at fast traverse until at a short distance before the final position it is slowed down to a creep speed. At the final position the drive is switched off and a clamp applied. If necessary the system can be so arranged that the final approach is always made from the same direction.

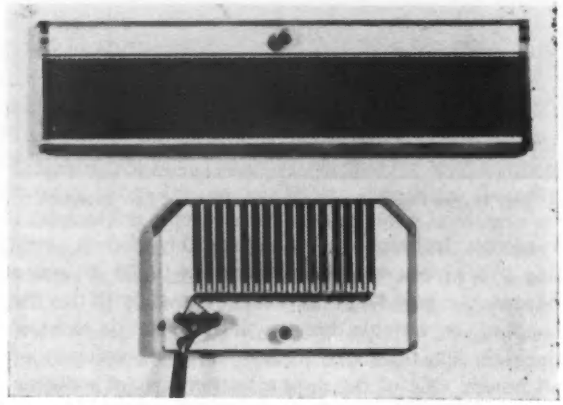


Fig. 11 The Inductosyn is a fine measuring element. It comprises two parts, the scale (top) and the slider (bottom) and consists of glass elements on which metallic conductors have been deposited

The machine control can be so arranged that the drilling operation becomes completely automatic. In this case when the table motions have reached the desired position a signal is given to the head control. The head feeds down to drill the hole and automatically retracts. At the end of retraction a further signal is passed to the tape reader to read the next position, and the cycle continues until the tape is finished.

3.2 Jig drilling machines

The accuracy required in the field of jig boring, etc, necessitates that the measurement of position must be made directly at the machine table. This is done by using the Inductosyn as the fine measuring element. The Inductosyn is the name of a measuring device developed by the Farrand Optical Co of the USA. It consists of glass elements on which metallic conductors have been deposited. There are two types of elements, termed the

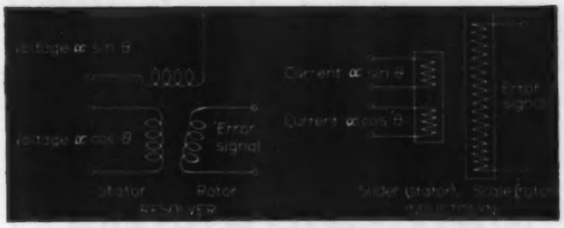


Fig. 12 The Inductosyn is analogous to a synchro resolver, but in a linear form. The correspondence between the two is shown here

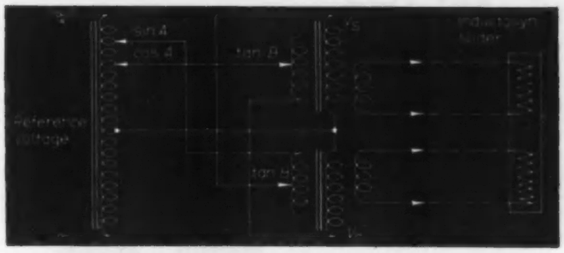


Fig. 13 A synthesizer unit for generating Inductosyn input signals

scale and the slider. The scales are about 10 in. long by 3 in. wide and are mounted end to end along the machine motion. The slide is about 3½ in. long by 3 in. wide and arranged to travel along the front of the scale elements with a gap between them of about 0·005 in. The slider is fed with signal currents which set up a magnetic field. The scales have induced in them a voltage which is a measure of the positional error signal. The elements are shown in Fig. 11.

The Inductosyn is analogous to a normal synchro resolver, but in a linear form. The correspondence between the Inductosyn and a resolver is illustrated in Fig. 12. The Inductosyn has a linear wavelength of 0·1 in., equivalent to one revolution of the resolver, so that it is a fine measuring element only, and is used in conjunction with other coarser measuring systems. Each linear position has a corresponding equivalent Inductosyn angle θ; thus 0·1 in. = 360°. The slider has two sets of conductors spaced a quarter of a wavelength apart. The conductors are actually spread over many wavelengths to produce an averaging effect. Signals at a frequency of 1000 c/s are fed to the conductors. The amplitudes of the signals are proportional to $\sin\theta$ for one set of conductors and $\cos\theta$ for the other. The signals set up a 1000 c/s magnetic field whose amplitude is sinusoidal with linear displacement. Thus the field has a null point at a linear displacement which is proportional to the angle θ. The scale has a single set of conductors which again extend over many wavelengths. The magnetic field induces a voltage in these conductors, which is zero when the scale has been given a linear displacement proportional to θ, that is the required linear displacement. The voltages induced in the scale about the null point are an indication of both the sign and the amplitude of the error. These voltages are used to control a servomotor.

The $\sin\theta$ and $\cos\theta$ signals can in fact be produced in a synchro resolver, in which case the resolver rotor is rotated and the $\sin\theta$ and $\cos\theta$ voltages induced in the stator windings are fed to the Inductosyn slider. Owing to the low resistance of the slider element, about 1 ohm, the signals from the resolver have to be passed through accurately matched buffer amplifiers.

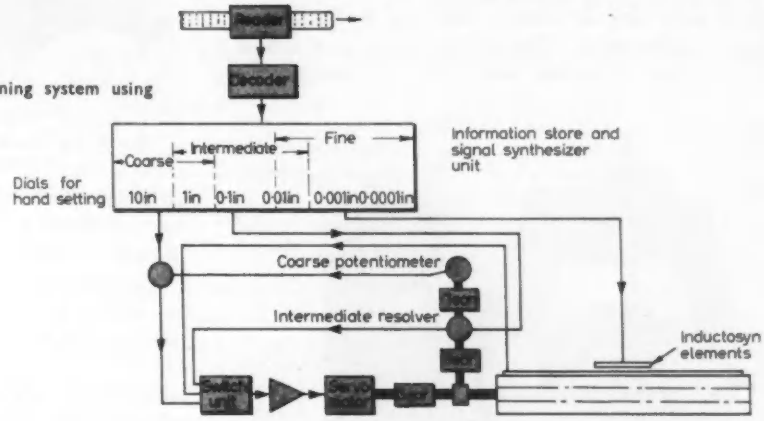
An alternative system which has been adopted is to derive the $\sin\theta$ and $\cos\theta$ signals in a synthesizer unit. This unit is composed of tapped transformers and switches, and by using a unique circuit the synthesizer unit is able to feed the Inductosyn slider circuit without the need for buffer amplifiers. The synthesizer unit is based on the trigonometrical relationships:

$$\sin(A + B) = \sin A \cos B + \cos A \sin B; \text{ and}$$

$$\cos(A + B) = \cos A \cos B - \sin A \sin B.$$

The output voltages are built up from angular increments of 36°, 3·6° and 0·36°, corresponding to linear increments of 0·010, 0·001 and 0·0001 in. respectively. A simplified circuit of the synthesizer unit for the case of two increments of angle is shown in Fig. 13. The transformer T1 is tapped to correspond to sin A and cos A, where A is in increments of 36°. Since the angle of A extends over 360° the transformer is centre tapped to produce both positive and negative signals. The transformers T2 and T3 are identical and have a primary winding coil and two secondary windings. One secondary

Fig. 14 A block diagram for a positioning system using Inductosyn elements



is tapped according to tan B, where B is in increments of 3·6°. Since B does not exceed 32·4° a single winding is sufficient. As will be seen from the circuit the following relationships can be derived:

$$V_s = \sin A + V_c \tan B$$

$$V_c = \cos A - V_s \tan B .$$

From these

$$V_s = \sin A + \cos A \tan A - V_s \tan^2 B = \frac{\sin A \cos B + \cos A \sin B}{\cos B\,(1+\tan^2 B)}$$

$$V_c = \cos A - \sin A \tan B - V_c \tan^2 B = \frac{\cos A \cos B - \sin A \sin B}{\cos B\,(1+\tan^2 B)}$$

$$\text{thus } \frac{V_s}{V_c} = \frac{\sin A \cos B + \cos A \sin B}{\cos A \cos B \pm \sin A \sin B} = \frac{\sin (A+B)}{\cos (A+B)} = \tan\theta$$

It will be seen that V_s and V_c are only approximately equal to $\sin\theta$ and $\cos\theta$, but that the ratio is exactly equal to $\tan\theta$. Since it is the ratio which is significant the circuit produces the desired result. The voltages V_s and V_c are developed across the transformers T2 and T3. Therefore a stepped down secondary on these transformers can be used to feed the Inductosyn slider conductors directly, without the need for buffer amplifiers.

As has been stated, the Inductosyn is a fine measuring system only, and cannot be used when the error exceeds about 0·030 in. Therefore an intermediate system and a coarse system are also required. The intermediate system is a resolver driven from the machine leadscrew. The gear ratio is such that the resolver has one revolution for 10 in. of table travel. The coarse system is a simple linear tapped transformer connected to a rotary stud

Fig. 15 An Atlantic co-ordinate drilling machine that uses the discontinuous position control system described in the text

switch. The switch is driven at an appropriate gear ratio. The resolver is fed from a sine, cosine synthesizer unit, similar to that used for the Inductosyn. The coarse transformer feedback voltage is compared with a demand signal voltage obtained from a linearly tapped transformer.

A block diagram for one axis of a complete system is shown in Fig. 14. The switching unit ensures that for errors greater than 3 in. the motion is under the control of the coarse system. For errors between 3 in. and 0·030 in. the intermediate resolver system becomes operative, and for errors below 0·030 in. the Inductosyn is in control.

3.3 Applications of discontinuous position control

The discontinuous positioning system that has been generally described is used in the control of a number of machines. A drilling machine is shown in Fig. 15. This machine has two motions of 2 ft 6 in. and 2 ft. It is fitted with recirculating ball ways and recirculating ball nuts and leadscrews. Inductosyns are used as the fine measuring element. The accuracy is better than $\pm$0·0002 in. along any axis, with a repeatability of $\pm$ 20 μin.

The servomechanism is of the continuous type using a split-field servomotor. The maximum traverse speed is

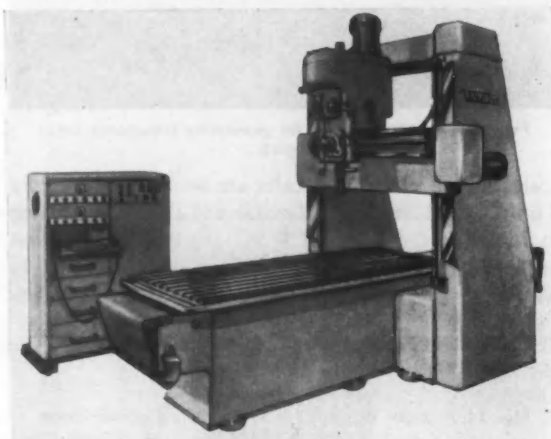


Fig. 16 The Wadkin co-ordinate drilling machine also uses discontinuous position control

60 in/min. Half motor torque is developed for a static error of 0·0001 in. and the machine table can be moved in steps of 0·0001 in.

A second example is shown in Fig. 16. In this machine the drilling head is mounted on a cross beam which in turn is carried on twin columns with power rise and fall. The table is 5½ ft × 3½ ft and runs on precision hardened and ground roller chain tracks, and is driven by a hardened and ground screw of 2 in. diameter using a preloaded recirculating ball nut. Inductosyns are again used as the fine measuring elements. The servo system is a switch-off-at-coincidence type powered by a 1 h.p. Ward Leonard set.

The system can also be used to control rotary tables using rotary Inductosyns as the measuring elements. The accuracy is $\pm$ 10 sec of arc with a repeatability of $\pm$ 5 sec. The rotary positioning system is being fitted to a 30 in. table using a more accurate Inductosyn. This will give a setting accuracy of $\pm$ 2 sec with a repeatability of $\pm$ 1 sec.

Acknowledgments

The author is indebted to the management of EMI Electronics for permission to publish this article.

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ESTIMATING DAMPING RATIO FROM FREQUENCY RESPONSE

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A KNOWLEDGE OF THE MANNER IN WHICH a system returns to a steady state after a disturbance is of critical importance in the analysis and synthesis of automatic control systems.

If the control engineer can estimate the value of the damping ratio ζ and the resonant frequency ω_r, or the natural frequency ω_n, of the dominant oscillatory mode, he has qualitative and quantitative knowledge of the dynamic performance of the system.

The methods presented here are derived on the assumption that the least damped roots, those associated with the principal oscillatory mode, dominate system performance during transient behaviour. For example, if the roots of the characteristic equation for a particular gain setting are located on the p plane as shown in Fig. 1, the transient solution for a sustained disturbance has the form:

$$\theta_o = Ae^{-p_1 t} + Be^{-p_2 t} + Ce^{-p_3 t} + De^{-at}\sin(bt + \phi)$$

where p_1, p_2, p_3, $a \pm jb$ are the roots of the characteristic equation.

If p_1, p_2, p_3 are large compared to a, their contribution to the output will have little significance since each will decay rapidly. The least damped roots will then dominate the system performance.

The curves of Figs. 2 and 3 and the construction in Fig. 4, are based on a simple quadratic response but may be used for approximating the behaviour of higher order systems if the least damped roots of such systems predominate.

When one of the real roots is close to the imaginary axis a system with a value of ζ as large as unity may exhibit a large overshoot. Under these conditions the damping ratio may give a misleading indication of the first overshoot magnitude but the response will never be more oscillatory than the simple quadratic for the same value of ζ.

When two or more pairs of complex roots lie near the imaginary axis of the p plane the curves do not apply since the response is not recognizable as a single damped sinusoid.

In higher order systems the most important use of these methods is in determining the 'relative stability'. Even though these methods yield only approximate results in finding the absolute value of ζ they are valuable in assessing whether a change in a particular system has resulted in a greater or lesser degree of stability.

METHOD 1: Phase margin ϕ_m

The steady state frequency response on open loop will yield the phase margin, that is the phase angle difference between 180° and that of the system when the gain is unity. Fig. 2 gives the relationship between the phase margin and the damping ratio.

Note that, for low values of ζ the curve is approximately linear and hence a useful approximation is

$$\zeta \simeq \frac{\pi}{360}\phi_m \simeq 0{\cdot}009\phi_m$$

METHOD 2: Resonant peak M_r

The maximum value of overall gain M_r may be obtained directly from an overall frequency response or by the use of M circles or M contours from open loop plots. Fig. 3 gives the relationship between M_r and the damping ratio.

METHOD 3: Construction on open loop polar plot

If the open loop frequency response is plotted in polar form and a semicircle drawn with unit diameter and centre $(-\frac{1}{2}, 0)$ as shown in Fig. 3, the ratio of QP to PO is 2ζ. The intersection of the semicircle with the response locus is ω_n.

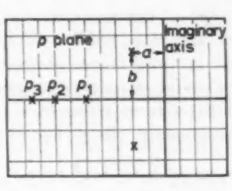


Fig. 1 Location of roots of typical system

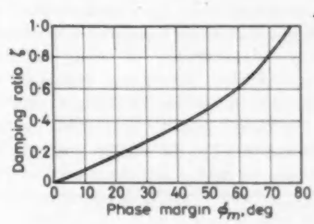


Fig. 2 Curve of damping ratio against phase margin, calculated from $\phi_m = \arctan 2\zeta\{(1+4\zeta^4)^{\frac{1}{2}} - 2\zeta^2\}^{-\frac{1}{2}}$

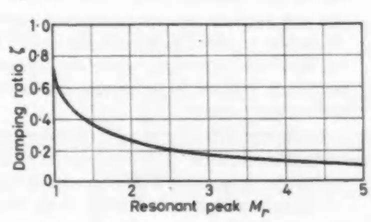


Fig. 3 Curve of damping ratio against resonant peak M_r calculated from $M_r = 1/[2\zeta(1-2\zeta^2)^{\frac{1}{2}}]$

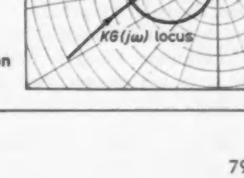
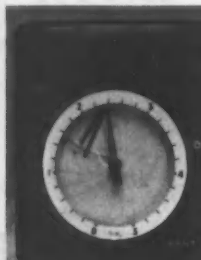


Fig. 4 Open loop construction for estimating damping ratio

CONTROL 8 SURVEY

One of the two basic types of recorder—the strip chart



And the other—the circular chart

by **C. W. MUNDAY**, B.Sc., A.R.I.C.
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Potentiometric recorders

IT IS OFTEN THOUGHT THAT CONTINUOUSLY-balancing potentiometer recorders are a relatively recent development, but in fact the idea of such a recorder was first conceived by Professor Callendar as long ago as 1886; and in collaboration with the Cambridge Instrument Co the world's first potentiometer recorder was produced in 1897.

The response of this type of relay-operated recorder to a step change in input will be a 'staircase' function. For systems with long time-constants in which changes are relatively slow this is no disadvantage. Developments in the oil and chemical industry demanded instruments that could accurately measure faster changes than the step by step recorder was capable of recording, and led to the modern continuously self-balancing potentiometer recorder. Advances in a number of fields have resulted in recorders in which full scale deflexion is achieved in ¼ sec.

In fact advances have been so rapid that the potential user is faced with a bewildering array of recorders of vastly different characteristics. Instrument engineers and specialists in this field will have no difficulty in choosing a suitable instrument for their requirements but the smaller user may find it useful to have a few comments on some of the features of available instruments.

Circular and strip charts

There are two basic ways of presenting the recorded information, namely on a circular chart or on a strip chart. These two types of chart meet different needs. The circular chart recorder is most useful for process control applications where it is very convenient to be able to see at a glance a 24-hour record of the process. The circular record is rather more convenient for batch type operations. Filing is very easy and paper costs are cheaper than strip chart recording.

The strip chart is the most convenient type of presentation for general laboratory and research applications. Its linear time scale is useful for the accurate measurement of time intervals. The 10 in. or so of pen travel enable the fullest use to be made of the recorders with $\pm 0{\cdot}25\%$ accuracy.

Applications

Temperature measurement with a potentiometer recorder should present few problems. All instruments calibrated in temperature (for use with a particular thermocouple) have built in automatic cold compensation. A wide range of control devices are available as extras which will enable many different types of control problem to be tackled. When the temperature of a process is being controlled by measurement of a thermocouple, most manufacturers offer as standard a thermocouple burnout or valve failure protection device. This makes the recorder drive slowly upscale simulating a rise in temperature and causes the appropriate alarm switch to operate.

In general thermocouple resistances are low and with short lengths of thermocouple lead 50 c/s pick-up problems will be small. Thermocouple leads should never run side by side with mains leads or trouble may result. Excessive hum pick-up overloads the record amplifier, makes the motion of the pen sluggish and increases dead space. Particular attention should be paid to earthing and screening when the thermocouple is inserted in a furnace heated by alternating current.

In the research laboratory a recorder may be used in a number of different applications and errors may result if the recorder is used with a source impedance much higher than that recommended by the makers. Manufacturing figures are generally conservative and use of a source impedance of 50% greater than the published figures may not do more than halve the accuracy of the recorder.

Analytical control by the recently developed technique of gas phase chromatography has made great progress lately and a substantial percentage of the current production of potentiometer recorders is taken up by chromatography. A general purpose recorder for gas chromatography ideally should have a scale span of 1 mV, balancing time of 2 sec, chart speeds in the range 12 to 240 in/h. A quick change gearbox for selecting the required chart speed is very desirable. Methods for integrating the record are also required. A transmitting slide wire which can supply a signal proportional to that from the detector is very useful. This auxiliary signal can be large enough to actuate an integrating device. The transmitting slide wire is being used as a simple but accurate electro-mechanical amplifier. In one method of integration the auxiliary signal drives an integrating motor and the shaft revolutions of the motor are made to actuate a solenoid-operated auxiliary pen at the side of the recorder chart. The integral of the signal is obtained by counting the 'pips'.

Recording of pH values is of considerable importance in the chemical industry. The glass electrode commonly used is a high impedance device and a pH meter must be used as an impedance changer so that a low impedance recorder can be used.

Recorders specially designed for direct measurements on high impedance sources are now becoming available, and many are used in reactor power level measurement.

The modern self-balancing instrument is so versatile that it is quite impossible in a short article to deal with all possible applications. Study of the recorder characteristics will repay the user many times. Appreciation of the optimum conditions for it will enable the user to get maximum benefit from a precision instrument.

Manufacturer	General Description	Error sensing element	Ranges	Power supply	Chart speeds	Chart size	
Cambridge Instrument Co Ltd Tick No 211	Cambridge, electronic, single point, self-balancing	Vibrating reed converter	0–1 mV — 0–60 mV 4 mV — 240 mV 10 mV — 600 mV	100/125 V 200/550 V 40, 50, 60 c/s	1 in. to 360 in. Using std gears. A 3-speed gear is available for ½ ×1 ×2	180 mm wide 40 ft or 100 ft long 10 in. visible	1
	Cambridge quick-acting electronic, single point 74151	Vibrating reed converter	0–1 mV — 0–60 mV	100/125 V 200/250 V 40, 50, 60 c/s	4½ in. to 6 in./min. Std lever-operated gearbox gives 6 speeds	180 mm wide 40 ft or 100 ft long	2
Research & Control Instruments Ltd Tick No 212	Electronic type PR12 2210A (Single point) type PR3210 A/00 (Multipoint)	Synchronous converter	20 ranges between 0–5 and 0–500 mV	220 V 50 c/s 72 VA	Gearbox gives ratios 1:4:7:5:30 on basic speeds of 20, 40, 80, 100 mm/h	25 cm wide, 25 m long Visible portion 25 cm	3
Foxboro-Yoxall Ltd Tick No 213	Dynalog electronic recorder. Circular chart recorder	3-pole vibrator	Minimum 0–5 mV	115 or 230 V 50 or 60 c/s	12 h, 24 h, 7-day rotation Other speeds by arrangement	12 in. dia. Pen travel 4½ in.	4
Electroflo Meters Co Ltd Tick No 214	Strip chart. Series 196	Galvanometer and oscillator amplifier valve	Minimum 0–6 mV	200–250 V 50 c/s	1, 2, 4 in/h	12 in. wide. 11 in. calibration 1000 h. Chart at 1 in/h Chart exposed 8 in.	5
	Circular chart. Series 197	Vibrator	0–5 mV	200–250 V 50 c/s 100–120 V 50 c/s	24, 12, or 0·5 h/rev	10½ in. dia. 4⅝ in. calibrated length	6
Honeywell Controls Ltd Tick No 215	Strip chart	Mains driven vibrator	Min. Std. Spans 2·5 mV	110–125 V 50 or 60 c/s Extra transformer for 230 V supply	Basic ½, 2 or 10 in/h	12 in. wide. Calibrated width 11 in. 100 ft long	7
			2·5 mV		Basic 2, 10 or 40 in/h	12 in. wide. Calibrated width 11 in. 100 ft long	8
			2·5 mV		Basic 6, 30 or 120 in/h	12 in. wide. Calibrated width 11 in. 100 ft long	9
			4·0 mV		Basic 6, 30 or 120 in/h	12 in. wide. Calibrated width 11 in. 100 ft long	10
			1·0 mV		Basic 4 or 120 in/min	12 in. wide. Calibrated width 11 in. 100 ft long	11
			5·0 mV		Basic 4 or 120 in/min	12 in. wide. Calibrated width 11 in. 100 ft long	12
	Duplex recorder for continuous recording of two variables on one chart	Mains driven vibrator	2·5 mV	110–125 V 50 c/s	Basics 30 in/h	12 in. wide. Calibrated width 11 in. 100 ft long	13
	Electronic function plotter, records $y = f(x)$	Mains driven vibrator	Y-axis (chart) 5 mV X-axis (pen) 5 mV	110–125 V 50 c/s	11 in. chart travel at traverse times of 15 or 5½ sec	11 × 11 in.	14
	Circular chart. Series 152X	Mains driven vibrator	2·5 mV	110–125 V 25, 50 or 60 c/s. Tsf for std mains available	Std 24 h/rev. 1, 4, 8 and 12 h. 7 days per rev also	12 in. dia. Calibrated width 4⅝ in.	15
					Std 24 h/rev. 1, 4, 8 and 12 h/rev. 4 and 24 min/rev also	12 in. dia. Calibrated width 4⅝ in.	16
					Std 24 h/rev. 1, 4, 8 and 12 h/rev. 4 and 24 min/rev also	12 in. dia. Calibrated width 4⅝ in.	17
Foster Instrument Co Ltd Tick No 216	Strip chart recorder	Synchronous vibrator	Min 5 mV full scale	220–240 V 50 c/s	Normal 15 mm/h. 2 months' supply at this speed	Effective width 8 in.	18
	Circular chart recorder	Synchronous vibrator	Min 8 mV full scale	220–240 V 50 c/s	1 rev in 24 h or 1 rev in 6 or 12 h, or 1 rev in 7 days	Dia. 10 in.	19
George Kent Ltd Tick No 217	Strip chart. Multelec Mk2	Galvanometer clamp and feelers	Min 6 mV (single point) 9 mV (multipoint)	110, 220–240 V 50 c/s	1, 2 or 3 in/h. Lever operated gearbox	Effective width 10 in. 120 ft long	20
	Strip chart, electronic. Multelec Mk2A	Synchronous converter	Min ranges 2 mV for low imped source. 30 mV for 10 megohm	220–240 V 50 c/s	1 in/h to 3 in/min as required	Effective width 10 in. 120 ft long	21
	Strip chart, electronic. Kent microvolt recorder	S'nous converter and pre-amplifier operate Multelec Mk2	100 μ V full scale	220–240 V 50 c/s	1, 2 and 3 in/h	Effective width 10 in. 120 ft long	22
	Strip chart high speed electronic. Multelec Mk3	Synchronous converter	30 mV with type 3 amplifier 2 mV with type 1 amplifier	210, 220, 250 V; 40, 50, 60 c/s	1, 2, or 4 in/h or 15, 30, 60 in/h	9⅞ in. wide	23
	Circular chart potentiometer recorder. Commander series	Synchronous converter	2 mV full scale to 2 V full scale	210–250 V a.c. 50 c/s	1 rev in 24 h or 7 days. 30 min, 1 h, 6 h, or 12 h rotation also	11 in. overall dia. Pen travel 4 in.	24
Sunvic Controls Ltd Tick No 218	Potentiometer recorder RSP2–Single point RSPM2–Multi-point	Synchronous vibrator	RSP2 0·5 mV–50 mV RSPM2 1·0 mV–50 mV span	200–250 V 50 c/s 100 W	RSP2: 1, 2, 3 in/h or min. RSPM2: 3, 6, 9, 15, 30, 45 in/h. RSP2: Lever speed selection	Width 9⅞ in. Length 120 ft.	25
	High impedance potentiometer recorder type RSP2 A		15 mV minimum. 20 mV, 25 mV, 30 mV, 40 mV, 50 mV, 75 mV and 100 mV	180–240 V; 40–60 c/s or 90–120 V; 40–60 c/s	1, 2, 3 in/min., 1, 2, 3 in/h or 3, 6, 9 in/h. 15, 30, 45 in/h	Width 9⅞ in. Length 120 ft	26
Bristol Instrument Co (Elliott Automation Ltd) Tick No 219	Dynamaster electronic self-balancing potentiometer recorder	Synchronous vibrator	Min ranges 5 mV f.s. for 10 sec or 10 mV f.s. for 3 sec response	110 V 50 or 60 c/s 200/250 V 50 or 60 c/s	1, 1½, 2, 3, 4, 4½, 5, 6, 9, 10, 12, 18, 20 and 24 in/h	Width 12½ in. 11 in. calibration 120 ft long	27
Integra Leeds & Northrup Ltd Tick No 220	Speedomax. type G rerecorder Model S. Strip chart recorder	Synchronous vibrator	Min span 200 μV. Max. span 1000 mV. 6 mV is std span	120 V or 240 V a.c. 50 c/s	Std speeds 1, 1½, 2, 3, 4, 6, 8 or 12 in/h. Automatic changer is available	10 11/16 in. 9⅞ in. calibrated 120 ft long	28
	Speedomax. Type G recorder model R. Circular chart recorder	Synchronous vibrator	6 mV std	115 V 50 or 60 c/s	Std 1 rev/24 h	10⅝ in dia. 9½ in. effective dia. 3½ in. calibrated rad.	29
	Speedomax. H. type recorder. Model S. Strip chart recorder	Synchronous vibrator	Min span 5 mV	115 V 50 or 60 c/s	1, 2, 3, 4, 6, 12 or 30 in/h as specified	6½ in. calibrated width	30
	Speedomax. Type H recorder. Model 12. Circular chart recorder	Synchronous vibrator	Min span 5 mV	115 V 50 or 60 c/s	One rev in 8 or 24 h	8 in. dia., 3 in. calibrated radius	31
	Speedomax. X-Y recorder Records the relationship between two variables	Synchronous vibrator	Standard range 10 mV X-axis 10 mV Y-axis	115 V 50 or 60 c/s	10 in in. 4 sec nominal	10 × 10 in.	32

Continued overleaf

CONTROL & SURVEY

	Response time	Standardization	Slide wire current supply	Accuracy	Positioning accuracy or dead space	Maximum permitted source impedance	Size and weight	No. of channels	Interval between successive printings
1	2 sec to re-balance after full scale change in input signal. Linear response to 0·25 c/s	Manual against Weston cell	1·5 V battery. Stabilized d.c. mains available	± 0·5% full scale	< 0·1% full scale	1–60 mV 500 ohms; 4–240 mV 8kΩ 10–600 mV 50kΩ	448 × 414 × 345 mm 34·9 kg	Up to 6	Normally 6 sec, but 3 sec can be obtained on request
2	Better than 0·4 sec full scale	Manual against Weston cell	1·5 V battery. Stabilized d.c. mains available	Better than ± 5 μV	Better than 1 μV	500 ohms for 1 mm full scale	800 × 414 × 345 mm 45·4 kg	Up to 6	Normally 2½ sec, 1½ sec to special order
3	Under 1 sec for full scale deflexion	Manual against Weston cell	Stabilized electronic supply	0·25% at full scale deflexion for all ranges of 5 mV and above	0·1% at full scale deflexion	To maintain 0·1% positioning accuracy 400 ohm/mV of span	422 × 510 × 367 mm 43 kg	2, 3, 4, 6 and 12	4 mm between points independent of chart speed
4	3 sec std. 1, 5, 15, 30 or 60 available	Continuous	No slide wire	0·25	0·01	10,000 ohms	17⅛ × 14⅜ × 11⅜ in. 70 lb	Up to 12 if colours repeated	6 sec
5	Full scale in 30 sec	Auto every 45 min on std. instr. Manual also provided	1·5 V dry cell	± 0·25%	0·1%	40 ohms	16½ × 23⅜ × 17⅛ in. 111 lb		
6	Full scale in 4 sec	Manual standardization	Stabilized current supply	±0·25% for 10 mV or more. ±0·025mV below	0·05% or 0·005 mV below 10 mV	40 ohms	17 × 14⅝ × 13 in.		
7	Series 153X10. Full scale travel 30 sec at 50 c/s or 24 sec at 60 c/s			± 0·20% or ± 0·02 mV for < 10 mV	0·03% or 0·004 mV for spans < 12 mV	300 ohms			30 sec f.s. travel. Series 153X60 (fixed cycle printing) 36 sec
8	Series 153X11. Full scale travel 15 sec at 50 c/s. 12 sec at 60 c/s			± 0·20% or ± 0·02 mV for spans < 10 mV	0·03% or 0·005 mV for spans < 15 mV	300 ohms			15 sec f.s. Series 153X65 (synchro balance) 7·2–18 sec
9	Series 153X12. Full scale travel 5½ sec at 50 c/s. 4½ sec at 60 c/s	Automatic		± 0·25% or ± 0·03 mV for spans < 12 mV	0·07% or 0·007 mV for spans < 10 mV	300 ohms	19¾ × 15⅝ × 13½ in. 85 lb	2, 3, 4, 6, 8, 10, 12, 16 or 20	15 sec full scale travel. Series 153X64 (fixed cycle printing) 18 sec
10	Series 153X17. Full scale travel 2·4 sec at 50 c/s. 2 sec at 60 c/s			±0·375% or ±0·045 mV for spans < 17 mV	0·07% or 0·012 mV for spans < 17 mV	300 ohms/mV or 2000 ohms total			5½ sec f.s. Series 153X62 (synchro balance) 1·2–6·0 sec
11	Series 153X18. Full scale travel 1·2 sec at 50 c/s. 1·0 sec at 60 c/s			± 0·25% or ± 0·045 mV for spans < 12 mV	0·07% or 0·012 mV for spans < 17 mV	1000 ohms/mV			5½ sec f.s. Series 153X72 (fixed time cycle) 6 sec
12	Series 153X16. Full scale travel ½ sec for 50 c/s or 60 c/s	Continuous standardizing using mercury cell	1·5 V dry cell	± 0·25%	less than 0·1%	30,000 ohms			2·4 sec f.s. Series 153X67 (fixed cycle printing) 24 sec
13	2½ or 5½ sec for full scale travel	Automatic		± 0·25%	0·007 mV	300 ohms/mV or 2000 ohms total			
14	5½, 15, 12 and 30 sec available for pen (Y-axis). 15 and 5½ sec for chart (X-axis)	Push button		Y-axis 0·5%. X-axis 5½ sec 0·25%; 12 sec 0·20%; 15sec 0·375%	Y-axis 5 mV 0·28%; 50 mV 0·14%. X-axis 0·10%	300 ohms each channel	19¾ × 15⅝ × 13½ in. 85 lb		
15	Series 152X13. Full scale travel 24 sec at 60 c/s. 30 sec at 50 c/s			± 0·25% or ± 0·03 mV for spans < 12 mV	0·03% or 0·004 mV for spans < 12 mV	300 ohms			
16	Series 152X14. Full scale travel 12 sec at 60 c/s. 15 sec at 50 c/s	Push button. Automatic standardization available as optional extra		± 0·25% or ± 0·03 mV for spans < 12 mV	0·03% or 0·005 mV for spans < 15 mV	300 ohms	16⅝ × 17⅞ × 12½ in.		
17	Series 152X12. Full scale travel 4½ sec at 60 c/s. 5½ sec at 50 c/s			± 0·25% or ± 0·03 mV for spans > 12 mV	0·03% or 0·007 mV for spans > 15 mV	300 ohms			
18	F.s. in 16 sec. Alternative balancing speeds at 8 or 32 sec. High speed recorder has 2·5 sec balance	Manual against standard cell	Constant voltage mains unit	For spans of 10 mV or above ± 0·25	For spans of 10 mV or above 0·10%	1000 ohms for 50mV span. 200 ohms for 10 mV span	546 × 366 × 325 mm 76 lb	Up to 6 channels	10 sec or 5 sec with high speed recorder
19	2·5, 8, 16 and 32 sec	Manual against standard cell	Constant voltage mains unit	For spans of 10 mV or above ± 0·25	For spans of 10 mV or above 0·10%	1000 ohms for 50mV span. 200 ohms for 10 mV span	546 × 366 × 325 mm 72 lb		
20	Full scale 20 sec	Automatic	Battery	± 0·33	0·10%	Impedance is roughly equal to the span in mV for optimum	17 × 19⅜ × 15½ in. deep 70 lb	2, 3, 4, 6, 8, and 12	2 channel–25 or 40 sec. 3, 4, 6, 8 and 12 channels–33⅓ sec
21	Full scale in 2 sec or 20 sec	Continuous	Stabilized to ± 0·05% against a standard cell	± 0·3 for non-suppressed ranges	± 0·1%	Type 1M, amp 500 ohms, 2M amp 5000 ohms, 3M amp 10M ohms	17 × 19⅜ × 15½ in 70 lb	2 and 3	
22	Full scale 20 sec	Automatic	Battery	± 7μV	± 0·1%	25,000 ohms	17 × 19⅜ × 15½ in. 92lb		
23	Full scale 2 sec	Continuous	5 mA. Servo stabilized to ± 0·1% against a standard	± 0·25%	± 0·1%	Type 1M amp 500 ohms, 2M amp 5000 ohms, 3M amp 10M	18 1/16 × 19⅜ × 13 3/16 in.	Up to 12 (special 16)	5, 10 or 20 sec
24	Full scale 2 or 15 sec	Continuous	Servo stabilized to ± 0·1% against a standard cell	± 0·25%	± 0·1%	Type 1M amp 500 ohms, 2M amp 5000 ohms, 3M amp 10M	17 13/16 × 15 × 13 5/16 in.		
25	2 sec full scale. A 1 sec response can be supplied in some instances for RSP2	Automatic for RSP2 at 15 min for RSPM2 is 60 min.	1·5 V dry battery	± 0·5% for ranges above 1 mV. ± 4μV for 0·5 mV range	0·1%	0–0·5 mV 100 ohms 0–1·0 mV 500 ohms 0–10 mV 1000 ohms	17 1/16 × 20 × 14½ in.	2, 4, 8 or 16	5 or 15 sec. Adjustable by sliding gears
26	2 sec full scale	Manual against standard cell every 1000 h.	Stabilized power supply	± 0·5%	Source impedance 300K ± 0·1; 1M ± 0·1; 10M ± 0·25	10 Megohms			
27	3 or 10 sec full scale	Automatic. Manual standardizing also fitted	1·5 V dry cell	± 0·25%	0·1%	9000 ohms for all ranges	15½ × 19 × 14⅞ in. 95 lb	2, 3, 4 and 6	4·6 sec, 8 sec, 15 or 30 sec
28	3 sec std, 1 sec non-std for instruments having a range > 10 mV	Automatic	Battery	± 0·3%	0·1%	3000 ohms for 6 mV span	20 × 18½ × 12⅜ in. 85 lb	2, 3, 4, 5, 6, 8, 10, 12, 16 or 20	4 sec standard
29	5·4 sec std, 3·6 sec non-std	Automatic	Battery	± 0·3%	0·1%	3000 ohms for 6 mV span	20 × 18½ × 12⅜ in. 85 lb		
30	1 sec full scale deflexion	Automatic every 48 min	Battery	± 0·5%	—	2000 ohms	12 × 11 × 11 in.		
31	1 or 5 sec full scale deflexion	Automatic every 48 min	Battery	± 0·5%	—	2000 ohms	12 × 11 11 in.		
32	X-axis 1 sec. Y-axis 1 sec	Manual	Battery	Y-axis ± 0·3% X-axis ± 0·3%	X-axis ± 0·1% Y-axis ± 0·1%	3000 ohms X-axis 3000 ohms Y-axis	20 × 18½ × 12⅜ in. deep 100 lb		

Display	Effect of 50 c/s pick-up	Recording device	Control devices	Zero suppression
Coloured dot	If signal has ripple of mains frequency special filter is required	Syphon pen. For single point recorder. Multipoint recorder uses turret pens with reservoir.	Comprehensive range of control systems is under development for use with recorder	Standard recorders with span of 1–60 mV can be provided with adjustable zero supp. up to 15 steps
Coloured dot	If signal has ripple of mains frequency special filter is required			
Coloured dots; or coloured dots and numbers	Permissible a.c. 50 c/s signal between input terminals is 1/1000 of range	Glass ink container and capillary stylus	Two point control (relay operation); propor. cont. with manual reset available	For laboratory work a multirange unit is available. Zero can be placed at 0, 20 40, 50, 60, 80 and 100 % of scale
Coloured dots	Not affected		Large variety of electrical and pneumatic control devices available	
	None. No d.c./a.c. conversion	Reservoir pen	2 or 3 position controls, also proportional controllers can be supplied	
		Stylus pen	2 position, 3 position. Modulating controls and proportional controllers available	
+ and numeral. Single colour or multicolour printing available.	Max perm d.c. on slidewire 80 V. 50 c/s comp of sig should be less than span	Single point recorders (30 sec to 2·4) use reservoir pens. 1½ and ½ sec models use ball pens. Multipoint use print wheel		A strip chart recorder with adjustable span and zero suppression is available.
		Reservoir pen	Auxiliary switch can be supplied on 1 pen for control purposes	Maximum suppression 50 mV
		Jewel-tipped pen		
		Non-corroding pen	Electrical proportional controller with automatic reset. Pneumatic control devices also available	Maximum suppression 50 mV
Coloured dots		Single channel syphon pen. Multipoint recorders stylus marking through endless multicoloured ribbon	Up to 4 cams for switching purposes can be fitted	Available if requested
		Capillary pen	Up to 4 cam operated switches and floating proportional control with reset can be supplied	Available if requested
2 point dot and dash 3, 4 and 6 point coloured dots.	Unaffected by 50 c/s hum	Syphon pen		Available if requested
Dot and dash (2 pt.) Dots (3 pt.)		Syphon pen	3 sets of alarm contacts can be provided on instruments not fitted with integrator	Up to 3 times scale span
	Filter unit built in to attenuate 50 c/s hum	Syphon pen	Alarm contacts can be supplied. A Kent ML20 air-operated controller can be fitted	
Multicoloured dots with or without numerals		Syphon pen	Air-operated controllers or transmitters available	
		Removable self-locating pen arm	Wide range of air operated controllers and transmittors available	Up to 3 times scale span
Dots and $\frac{1}{8}$ in high figures	Negative input terminal is earthed	Syphon for single point. Single colour printing (red) and $\frac{1}{8}$ in. high numbers		5 ranges of suppression can be effected by a selector switch
		Syphon pen	Cursor pattern or cam-operated microswitch type alarm contacts can be fitted.	
Contrasting dots or contrasting dots and numbers	50 c/s ripple should not exceed 5 mV	Syphon pen	Electrical on/off two position, three position and floating control available.	Up to 100 mV suppression can be be supplied
Coloured dots and coloured dots and numerals	3-stage filter provided to minimize effect	Syphon pen	Wide range of controls available	Can also be provided up to a ratio of 10:1 of starting point at span in mV
		Pen		
		Pen	A wide range of control systems available for use with this instrument	
		Pen		
			Control and alarm contacts can be supplied for X-axis only	

Remarks

Cambridge Instrument
Single point recorders can have up to 6 independent adjustable cams operating single pole change over microswitches at pre-determined recorder settings. Multipoint instruments can have cams to provide on/off control on all points independently. Solenoid-operated stylus can be fitted to mark left-hand edge of chart with event lines

Series 74151
Can also be supplied as self-balancing d.c. bridge. Span down to 10 deg C using resistance thermometer. Can be used as self-balancing d.c. ratiometer for measuring ratio of quantities that can be applied in form of voltages or currents. Events recorder as above.

Research and Control Instruments
Relay-operated stylus marks left-hand side of chart
Permissible a.c. 50 c/s signal between input terminals and earth is equal to range. Maximum permissible d.c. level between input terminals and earth is 1000 × range with maximum of 30 V

Foxboro-Yoxall
No slidewire is used in this instrument. The voltage is compared with a standard cell in an all-capacitance bridge. By means of a 3-pole vibrator the capacitances are periodically connected and changes compared. Any error is servo corrected

Electroflo Meters
The 196 is now available with synchronous vibrator and balancing motor used in the Series 197 potentiometer

Honeywell Controls Ltd
Strip chart
In fixed-cycle time operation of multipoint recorder, print wheel registers at definite time intervals. In synchro balance printing, each point is printed as soon as instrument balances. If the recorded variables are close together the time interval between records is a minimum. Rapidly changing variables are more accurately recorded. All recorders for temperature control can have a thermocouple burnout protection device. If the thermocouple burns out the recorder drives up scale. Smaller spans than standard can be obtained on request. 1 and 2-way event pens available
Duplex
Vertical displacement between pens ½ in. 1-way and 2-way solenoid.
Function plotter
Incorporates two measuring systems. One variable drives pen. Other variable drives chart

George Kent Ltd
Strip chart, electronic Kentmicrovolt recorder
The d.c. potential is filtered and compared with a reference voltage from 0–100 mV slidewire through a 1000:1 attenuator. Any error signal is amplified by synchronous converter and amplifier and the rectified output fed to the galvanometer of the Multelec Mk2 instrument
Commander series
Upscale or downscale drive in event of external circuit failure is a built-in feature

Sunvic Controls Ltd
Multitrace recorder RSPM2 can have fast/slow recording facility. In 'fast' position recorder records 16 points in 75 sec. In 'slow' position instrument records 16 points every 15 m n.
Provisional specification for recording d.c. potentials of 0–100 mV across any impedance not exceeding 10 megohms

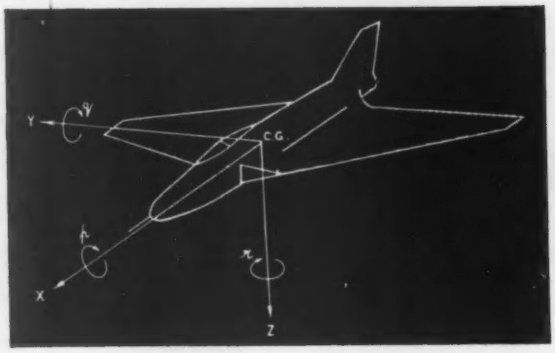
Bristol Instrument Co
Scale span may be altered by changing range plug. 2-way solenoid-operated event pen available
Air-operated controllers with proportional, proportional and integral, proportional and derivative, and three term controllers are available

Integra Leeds
Type G Models
Greater sensitivity up to 50 μV span or source impedance up to 500 MΩ can be provided by a use of special input amplifiers
X–Y records
If more sensitive ranges, or higher source impedances are required special pre-amplifiers can be fitted. If these are used minimum ranges are X-axis 100 μV, Y-axis 1 mV.

MAKING AIRCRAFT SYSTEMS WORK

PART I—SYSTEM SYNTHESIS

Fig 1 Aircraft axes



Short & Harland's Foody & Mills see the provision of automatic control or stabilization for an aircraft, as a system study which proceeds from simulation to flight clearance

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THE DESIGN, CONSTRUCTION, TESTING AND FINAL FLIGHT proving of an automatic control or stabilization system for an aircraft form a system study which starts with an evaluation of the overall requirements, and does not end until the system is acceptable over the required flight envelope. We start, therefore, by discussing the synthesis problem of choosing a system which will meet the specification in all its ramifications, and continue step by step through the design process until complete flight clearance is obtained. Our approach hinges on the early provision and continuous utilization of a system simulation which begins as an analytical representation but gradually fills out with system components as they become available. This ensures that non-linearities are properly catered for and petty malfunctionings are traced before the flight test stage is approached. The explanation and rectification of flight test behaviour is also eased by simulation, and long and tedious flight test hours are saved.

Basic aircraft characteristics vary considerably but we can usually explain the differences and know sufficient of the problem to predict the likely characteristics early in the design. The basic aerodynamic design should be such that the aircraft is fundamentally stable and manageable when in a stick-fixed condition, but this is not always possible and we may be faced with the introduction of a system on which the safety of the aircraft depends. Apart from this, however, control requirements can differ considerably; for example, the characteristics of a high speed fighter are very different from those of a long range freighter. The first part of this article covers the field generally, showing how various

characteristics and requirements can be reconciled and giving the practical standards of performance which can be expected from a control system.

BASIC AIRCRAFT CHARACTERISTICS AND CONTROL REQUIREMENTS

Longitudinal control problems

When discussing basic aircraft characteristics it is usual to divide the freedoms into longitudinal and lateral sets. The longitudinal sets involve freedom in X, Z and in pitching, whilst the lateral sets involve freedoms in Y, rolling and yawing (Fig. 1). Initially, it can be assumed that these sets of freedom are independent and the longitudinal set breaks up into a long-period poorly damped oscillation, and a short-period oscillation which is usually well damped. The long-period, or *phugoid*, oscillation can have a period of the order of one minute, and is seldom much trouble as its frequency is well within the capabilities of human pilotage. However, it does lead to excessive fatigue in protracted flying and is, therefore, an oscillation which could well be looked after by the autopilot.

The short-period oscillation, however, has a period which, depending on the aircraft characteristics, might be of the order of 2 to 3 sec. This oscillation is very often dead-beat and is well damped, except possibly in some transonic conditions. It is beyond the reaction capability of the pilot, so that its stability is, therefore, important and must be achieved by aerodynamic rather than automatic means, unless a fail-safe condition is evolved.

If trouble is experienced in the longitudinal plane, the main aircraft variables at the disposal of the designer are the damping in pitch achieved by a change in size of the stabilizing surfaces, and the static margin which is, to a large extent, a function of centre-of-gravity position. This, however, is usually very tightly controlled for reasons other than those of dynamic stability. Another factor which influences the damping of the phugoid oscillation is the lift coefficient.

Elevator and throttle control

Improvements can, of course, be achieved by the introduction of automatic terms. In general, it is desirable to make the aircraft satisfactory aerodynamically, and then install an autopilot to maintain constant values of speed, incidence, and longitudinal attitude without human supervision, and to suppress any accidental disturbances from equilibrium conditions. This can be accomplished with the elevator and the throttle, the most common form of control being to apply elevator to counteract a pitching disturbance. This effectively damps the phugoid oscillation and can, if required, be arranged to make it dead-beat with the appropriate sluggishness in response, as shown in Fig. 2. The penalty paid is in a reduction of damping in the short-period oscillation and also an increase in its frequency.

Another common form of control is that in which the elevator is moved owing to a speed variation. A simple form of feedback of a signal proportional to speed variation from a datum is not always satisfactory, and a phase advance in which rate-of-change of speed is used may be necessary. The effect of this combination is shown in Fig. 3. This form of control is as powerful as attitude control and is now widely used in autopilot work.

Height holding is also important, and can be achieved by feeding a combination of attitude and height error to the elevators. Fig. 4 shows a typical response to a pitching-moment disturbance for an attitude control with the addition of height feedback. However the addition of this simple height term means that a steady state error in height from datum value will exist and this can be corrected by the introduction of an integral of height signal (Fig. 5).

In throttle control, there is normally a significant lag before a throttle demand gives a change of thrust, and so this control cannot look after short-period oscillations. The throttle can, however, be used as a speed control

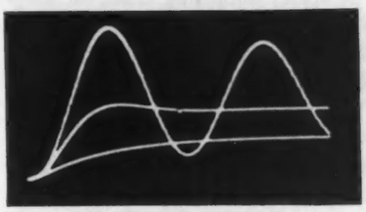


Fig. 2 Elevator controlling attitude

Effect of η (elevator angle) $= a\,\theta$ control on phugoid stability
A. Free aircraft ($a = 0$)
B. Stabilized aircraft ($a = 0{\cdot}1$)
C. Stabilized aircraft ($a = 0{\cdot}5$)
Pitch angle due to throttle movement. Sweep time, 100 sec

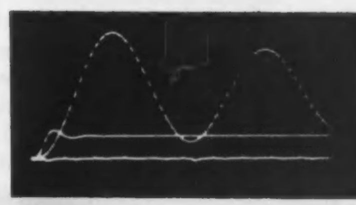
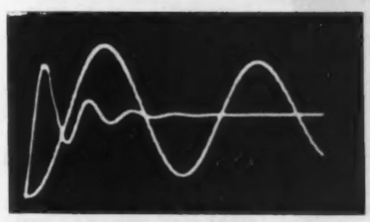


Fig. 3 Elevator controlling speed

Effect of $\eta = b\,(\bar{u} + \dot{\bar{u}})$ control on phugoid stability
A. Free aircraft
B. Stabilized aircraft (1°/3 knots i.a.s.)
Pitch angle due to throttle movement



NOTE: Refer to Fig. 2 for the relative positions of curves A and B

Fig. 4 Height lock control with height feedback

$\eta = 0{\cdot}5\theta + ch$ ($c = 1°/20$ ft)
A. Free aircraft
B. Stabilized aircraft
Height error due to pitching moment

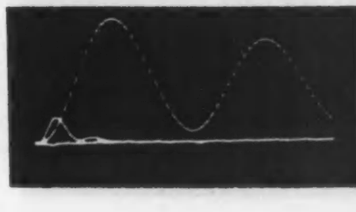


Fig. 5 Height lock control with integral of height feedback

$\eta = 0{\cdot}5\theta + c(h + 0{\cdot}1\int h\,dt)$
($c = 1°/20$ ft)
A. Free aircraft
B. Stabilized aircraft
Height error due to pitching moment

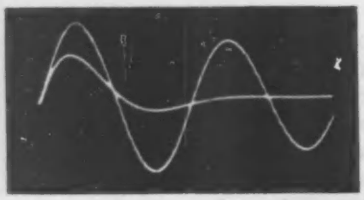
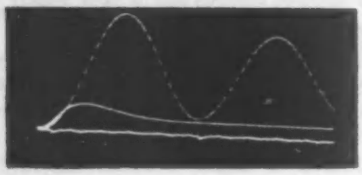


Fig. 6 Effect of throttle as a speed control (*left*)
A. Free aircraft
B. Stabilized aircraft
($T = d\bar{u}$ where d is 200 lb/knot i.a.s.)
Speed response to drag change

Fig. 7 Effect of throttle as a height control (*right*)
A. Free aircraft
B. Stabilized aircraft
($\eta = 0{\cdot}5\theta$ Throttle movement $T = kh$ where k is 5 lb/ft)
Height response to pitching moment



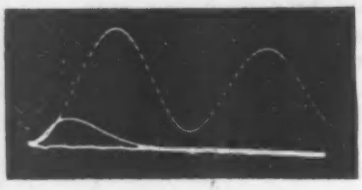
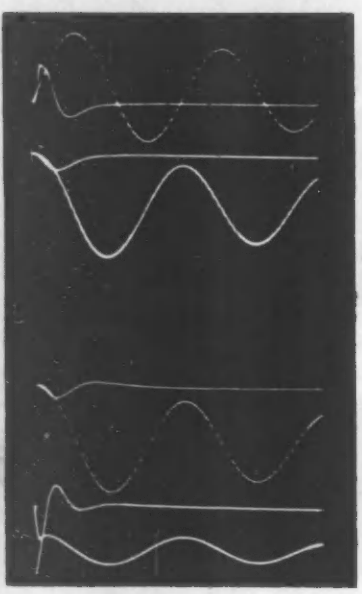


Fig. 8 Effect of throttle as a height control (as Fig. 7) with addition of integral of height feedback (*left*)

(Fig. 6), where the powerful stabilizing effect for long-period oscillation is obvious. Throttle can also be used as a height control in a similar fashion to elevators, and the result of this form of control in conjunction with elevator control of attitude is shown in Fig. 7. Again, a simple height feedback produces a steady state error and the effect of the introduction of an integral term is shown in Fig. 8.

The choice of a desirable control system depends largely on the range of conditions to be catered for. Fig. 9 shows a practical case of the improvement in stability which has occurred on the introduction of an automatic control system. A rate-of-pitch feedback has been used and the normal effect of this is to add further damping to both the phugoid and short-period modes. The particular feedbacks were optimized over a wide speed range and better results could have been achieved at any particular speed.



θ (attitude)

h (height deviation)

Fig. 9 Effect of stabilization on the longitudinal oscillations in straight and level flight

$\eta = \theta + 0{\cdot}5\,\dot{\theta} + k_1(h + 0{\cdot}1\int h\,dt)$

$T = k_2(\bar{u} + \dot{\bar{u}})$

($k_1 = 1°/20$ ft, $k_2 = 200$ lb/knot i.a.s.)

Aircraft response to pitching moment

$\bar{u}$ (forward speed deviation)

$\bar{w}$ (incidence)

Lateral control problems

The lateral set of equations on the free aircraft represent a *Dutch roll* oscillation of various degrees of damping, and shortish (3–5 sec.) period, together with a movement which, in effect, produces the characteristics of a slow change in heading and can be stable or unstable. This is known as the *spiral mode*, and like the phugoid in the longitudinal case is not a serious embarrassment to the pilot even when divergence exists.

The Dutch roll oscillation is of most interest. For satisfactory handling characteristics it is not sufficient for this oscillation to be damped; if possible, it should have a period long enough for the pilot to control it. This brings us to the problem of what the pilot can be expected to do and at what stage in an instability it is necessary to bring in automatic aids. Fig. 10 gives an indication of the relationship between the period and the damping of an oscillation, specifically the Dutch roll, for satisfactory handling characteristics. The normal pilot

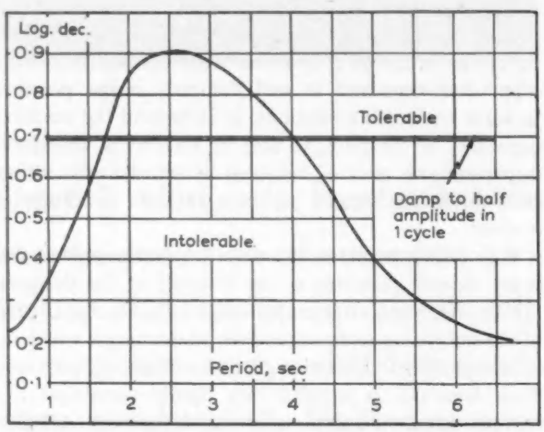


Fig. 10 Relationship between period and damping of a Dutch roll oscillation for acceptable handling characteristics

requires good damping in a very short period oscillation, but as the period goes up he will accept less damping as he can begin to exercise some measure of control over the oscillation. As the period gets longer the effect of damping is masked, the oscillation becoming more sluggish even though quite controllable. These results have been obtained from simulator work with some flight test correlation and appear to be a reasonable guide to what the pilot can achieve.

Aerodynamically, of course, various possibilities exist by which the characteristics of this oscillation can be improved but they are generally at the expense of decreasing stability in the spiral mode. The main aerodynamic variables at the disposal of the designer are fin size with its primary effect on yawing moment due to sideslip, and wing dihedral with its primary effect on rolling moment due to sideslip. In normal configurations

it is usually possible to get a fin size and dihedral angle to give satisfactory stability. But in the modern low aspect ratio, swept wing—especially when these wings are placed high on the body—an increased fin size, whilst increasing the damping, also decreases the period so that handling characteristics are not improved. Sometimes one cannot get enough anhedral on to effect any significant reduction in rolling movement due to sideslip. This again is a function of wing lift coefficient and compromises can usually be achieved.

Turning to automatic control, it is usually found quite adequate for straight and level flight to feed back a signal of bank angle and rate of roll to the ailerons, and yaw and rate of yaw to the rudder. It is sometimes desirable to feed the rolling signal to the rudder and dispense with the yawing signal altogether but, in general, no significant difficulty is experienced. A typical result for an aircraft flying at low speed is shown in Fig. 11.

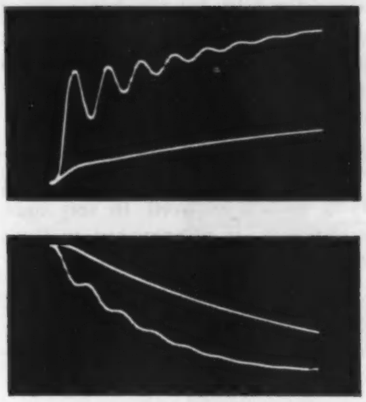


Fig. 11 Effect of stabilization on the lateral oscillation in straight and level flight

Aileron angle $\xi = \phi + \dot{\phi} + \psi + \dot{\psi}$
Rudder angle $\zeta = \psi + \dot{\psi}$
Aircraft response to side gust. Sweep time, 33 sec

Stability in turning flight

The problem of stability in turning flight is not as susceptible to analysis as the normal straight and level condition. This is due to the non-linearity of the describing equations and the difficulty of obtaining acceptable values of the coefficients in the equations. The problem cannot be split up into longitudinal and lateral sets; therefore, the complete set of aircraft freedoms must be considered. Various approaches are possible, the main problem being that of stability and height holding at high angles of bank. In a practical design it has been necessary to feed a height signal to the ailerons in order to achieve a reasonable degree of stability and co-ordination, and the feedbacks in the turning configuration are shown in Table 1. In general, owing to limitations in information and equipment available, optimizing of the turning flight system has been necessary in flight, rather than by analytical means; obviously this is expensive and time-consuming.

Table 1. Control equations in turning flight

Elevator angle $\eta = a_1 (q - q_c - \dot{\theta}_p) + a_2 (\theta - \theta_p)$
Aileron angle $\xi = b_1 (p - p_c - \dot{\phi}_p) + b_2 (\phi - \phi_p) + b_3 h + b_4 \int h dt$
Rudder angle $\zeta = c_1 (r - r_c)$

where

p =	roll rate	q_c =	computed pitch rate
q =	pitch rate	r_c =	computed yaw rate
r =	yaw rate	ϕ_p =	roll platform setting
p_c =	computed roll rate	θ_p =	pitch platform setting

Control versus stabilization

We have discussed methods by which stability in a given flight condition can be maintained in the presence of external disturbances. It is obvious that it is often necessary to exercise a measure of control over the actual flight condition: we might define 'control' as the problem of achieving a desired flight path, and 'stabilization' as the problem of maintaining this flight path as accurately as possible.

The basic task of the autopilot in most aircraft is to assist the pilot by maintaining a flight condition set by him and also to carry out co-ordinated command turns. Thus it is possible for the pilot to trim the aircraft in the selected condition and leave it to the autopilot to apply what might be described as second-order corrections. If, however, we extend the operation of the autopilot so that command manoeuvres may be performed, it is both stabilizing and controlling. It must have considerable authority to do this, and the problem therefore arises of making sure that if a fault develops, disengagement can be carried out quickly.

An autopilot may be called upon to control an aircraft which is fundamentally unsafe without it. In the event of a fault occurring, it is not sufficient merely to disengage but some duplicate system must be available to take over. Thus, whilst the mechanical and electrical problems of designing a complete command control system are not a major obstacle, the reliability and fault isolation characteristics can, in general, be very tricky.

The introduction of autostabilizers into aircraft control systems began on an *ad hoc* basis, and instances spring to mind of unexpected trouble occurring in lateral oscillations which were corrected by the incorporation of an autostabilizer. This began as a low power signal of limited authority which provided increased stability at the expense of response to actual control movement. It is obvious that the more unstable the aircraft is in the free case, the higher the authority of the autostabilizer must be, so that occasionally the autostabilizer has equivalent authority to the basic contiol. This again leads to problems of safety; duplication, triplication and even quadruplication have been considered as a remedy.

In general, then, great care must be exercised in choosing a control system, and it is best to limit its authority as much as possible. The occasion does arise in which autopilots and autostabilizers are essential

but aerodynamic rather than automatic stability is to be preferred.

Analysis and detailed specification

The first step in the analysis of a system is the determination of aerodynamic coefficients or derivatives. For example, it may be necessary to consider motion in an accelerated condition, or to consider the coupling of the lateral and longitudinal degrees of freedom.

This is a task for the aerodynamicist with the assistance of wind tunnel tests, but at the start of a project the information is often insufficient for an accurate estimate. It is then necessary to fall back on empirical methods.

Fig. 12 Handling simulator for blind flying conditions

After deciding upon the dynamic representation and the associated derivatives, the next step is to examine the various conditions of the system over the complete range of the flight envelope. This is normally carried out on analogue computers and the initial object, in conventional cases, is to ensure that the basic aircraft displays reasonable dynamic characteristics.

This may be difficult, especially where significant departures from existing experience are involved, and attempts have been made to solve the problem by the use of handling simulators. These are general purpose units on which basic characteristics can be altered, and the unit shown in Fig. 12 represents blind flying conditions. This can be made to yield valuable design information and has proved very useful in system evaluation.

Aerodynamic changes are, in general, confined to changes in fin and dihedral. There is, however, one other variable which is often under the control of the designer, and that is the product of inertia about the roll and yaw axis. This is a very significant variable and particular attention should be paid to it at an early stage, especially with low aspect ratio wings.

Elements in a control system

Having gone as far as possible by aerodynamic means towards meeting the requirements, the problem of detailed specification of automatic equipment arises. A typical single loop of a control system is shown in Fig. 13. It is necessary to provide sensing equipment to pick up changes in angular position or changes in such items as airspeed. These latter are signals fed to an air data computer which prepares the information for feeding to the controls. The output of the computer is normally fed to a junction or relay box which is designed to switch in various functions as demanded, thence to an amplifier into which command signals can also be fed, and finally to the control actuators which apply the appropriate moment or force to the aircraft.

The pitot sensing equipment must operate over the performance range of the aircraft and this goes a long way towards specifying what is required. In very tight performance bands, however, it is necessary to limit the accuracy and sensitivity of this equipment.

In fixing the specification of the angular sensing equipment, the aircraft performance necessary under automatic control must be considered. This equipment normally consists of a free gyro whose performance may well be determined by the accuracy of flying required where other navigational checks are available to the pilot. Accuracy in the free gyro is not of primary importance. If navigational checks are not available the performance of the free gyro may become critical, the limiting case being reached in missiles where an inertia technique coupled with a very precise gyro is essential.

Rate gyros are common elements in autopilot systems and are used about all three axes. For the conventional type of autopilot where no excessive manoeuvres are called for, it is sufficient to have a linearity in the rate gyro output up to something of the order of 20°/sec and a resolution of the order of $\frac{1}{4}$°/sec. When rates in excess of this are called for, care must be taken to ensure that a sufficient range of operation is specified in the rate gyro. The dynamic equations will indicate *maximum rates* to be catered for in both imposed manoeuvres and in random disturbances. If manoeuvring and control are demanded in the landing configuration through the autopilot, turbulent air condition may impose higher rates on the aircraft.

Computation

The air data computer normally accepts pitot and static pressures and ram temperature, and, using either analogue or digital techniques, computes true airspeed, barometric height, indicated airspeed, Mach number and rate of climb. Some of these are merely fed to display instruments and then their accuracy is not of fundamental importance, but in more modern autopilots the

accuracy of turns computation will depend on true airspeed and height holding on the barometric height-lock signal. A Mach number flight law with light tolerances is often specified for military aircraft, so that small errors will bring the aircraft into the buffet region. Thus there is, in general, a requirement for accurate computation of air data information. For control purposes, an analogue approach is probably adequate but if navigation and accuracy over a long period is in question then digital techniques may be necessary.

It is unlikely that in a modern autopilot the same set of feedbacks can be used universally throughout the flight range. Each condition involves the same type of sensing equipment but often a different form of feedback,

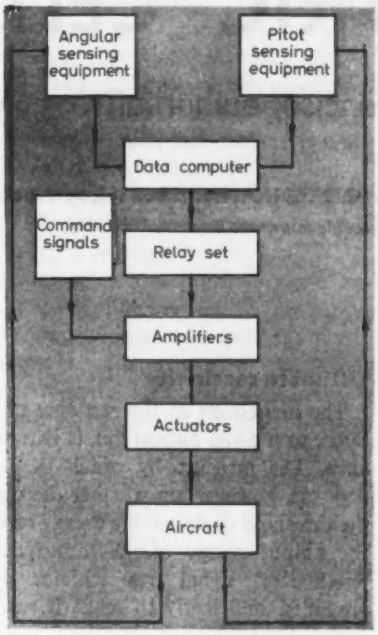


Fig. 13 Typical elements in a control system

and provision for switching the functions of the various elements, is provided in the relay set.

The outputs of the sensing elements are often at a low power level and considerable amplification is required to operate the actuators. The amplifiers, in addition, usually act as mixing units for combining the variety of signals which may be used for control. The sensing unit outputs are routed to the amplifier via attenuators, and in simple systems it is often possible for one set of attenuator values to provide signal strengths suitable over the altitude and speed ranges of operation of the system. In recent years, however, autocontrol has been used on aircraft over very wide speed and height ranges so that variation of the attenuator settings as a function of airspeed, height or Mach number is necessary. This is provided in modern autopilots and is often obtained by using the appropriate output of the air data computer to control a motor which drives the potentiometer attenuating the control signal.

Magnetic amplifiers are widely used in autocontrol systems, several stages in cascade normally being necessary to obtain sufficient power output. Recent trends, however, have been toward transistorized amplifiers owing to the great saving in space and weight and their ready adaptability to printed-circuit techniques.

Actuation and disengagement

The determination of a suitable actuation system depends on many factors. Consider an autopilot actuator driving the control surfaces directly. Either a hydraulic or an electric system can be used but preference nowadays is for the hydraulic. The hinge moments on the surfaces throughout the speed range must be known so that a surface position demand can be met by the available torque.

It may be important to specify the rate of control movement, thus fixing the horsepower necessary. However, the problem is not the provision of adequate horsepower in the actuator but to ensure that, at all points in the flight envelope, a malfunctioning or runaway does not cause any structural damage to the aircraft before the pilot can disengage. It will be appreciated that the stick force per unit normal acceleration, especially when subjected to Mach number effects, is a doubtful item and if this becomes very low, great difficulty may be encountered in ensuring that a dangerous positive or negative angular acceleration cannot be applied to the aircraft. Various methods are available to cater for this, such as a 'break link,' so that when an excessive control force is demanded, automatic disengagement follows. An independent monitoring circuit for comparison purposes has been tried on some autopilots. The trouble, however, is in ensuring that inadvertent disengagement does not occur. It can also happen that this form of protection alone is not acceptable throughout the flight range, and recourse is made to an arrangement which allows a certain position band on the control surface and will trip the autopilot if this band is exceeded.

Alternatively, suppose the autopilot actuator operates upon a power control system, either through the channel controlled by the pilot or through an alternative channel. Various forms of integrated system are available in which stabilizing signals are not fed back to the stick and in which at the same time the pilot has adequate control in an emergency.

In the synthesis of an automatic system for aircraft control purposes, considerable latitude in the specification of the elements in the control loop exists initially. However, it must be realized that serious linearizing assumptions are, in general, made at this stage and quite unexpected characteristics can develop if too much tolerance is allowed on fundamental control items. The object of the designer should be to produce as tight a specification as current practice will permit. If concessions are to be made, this should be done only at the simulation and design crystallization stage, which will be discussed in Part 2.

To be continued next month

Semiconductors will be used increasingly as photocontrol devices

PHOTOELECTRIC CELLS

—a concise, authoritative guide

by **K. M. GREENLAND**, B.SC., PH.D., F.INST.P., F.R.M.S.
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OPTICAL RADIATION OF ANY WAVELENGTH CAN BE measured in terms of an electrical quantity. The limits of the optical spectrum are no longer clearly defined (as they were when the human eye was the only available detector), but in this survey I shall take optical radiation to include the ultra-violet region, visible light, and the infra-red region up to the limit of response of photoelectric detectors. At the present time this limit is at a wavelength of about 10 μ.

What is a 'photoelectric transducer'?

While it is true that photoelectric transducers of one kind or another cover the whole of this region and, indeed, are sensitive to X-radiation and γ-radiation as well, the principles of operation, the characteristics and the physical form differ very widely from one type to another; in regions where there is a choice between two or more kinds of phototransducer a careful assessment of the characteristics of the transducer itself and of the auxiliary optical and electrical equipment must be made if efficiency and economy are to have due consideration.

By 'photoelectric transducer', or 'photocell' for short, is usually meant a transducer in which each effective photon produces an electrical or electronic event directly. Not all radiation transducers are of this kind: thermal transducers such as bolometers, thermocouples and electropneumatic devices give electrical signals in response to the absorption of radiation but only through the change of electrical properties due to a rise in temperature of the receiver. These thermal devices do not come within the scope of this review.

Ultimate sensitivity

The magnitude of the response of a radiation transducer to a given optical flux is naturally of first importance. The measure by which the response is judged depends, however, on whether the optical signal is near the threshold of detectable energy or well above it. Since the output energy of the transducer is electrical any 'intelligible' signal can without great difficulty be amplified sufficiently to make it readable or otherwise useful. For very weak radiations, therefore, the electrical noise generated by the transducer, rather than its output, generally puts a lower limit to the measurable energy. The input power giving signal/noise ratio of unity for a bandwidth of 1 c/s is usually quoted as a measure of this limit and the value is known as the ***ultimate sensitivity*** or ***noise equivalent power*** of the transducer. Of course, if the transducer noise is very low it becomes more difficult to provide an amplifier which enables the sensitivity to be fully exploited, since the amplifier itself introduces noise which may mask the signal.

Applications of photoelectric transducers where ultimate sensitivity is significant are commonly met in spectrophotometry. In this method of analysis one must define very narrow wavebands in order to achieve high resolution, so that only a minute fraction of the total energy of the source is selected; moreover, the method of selecting the wavebands necessitates the use of very small linear apertures and rather small angular apertures, so increasing the difficulty of utilizing the limited energy of the source. The source itself may be of low intensity as it is, for instance, in fluorometry. Thus, while photocell

noise may be very low the ultimate sensitivity of a photocell is still important in many industrial applications.

Sensitivity or responsivity?

When the intensity of radiation is high enough to raise the output considerably above the noise level, the ratio of the electrical output of the transducer to the incident radiation energy is of more practical interest than the ultimate sensitivity. Instrumentation in the realm of higher signal inputs is usually less elaborate and economy in amplification comes to the fore: the output/input ratio determines the amplification factor. This ratio is commonly known as *sensitivity* but to avoid confusion with ultimate sensitivity an alternative term is now coming into use: *responsivity*. For infra-red detectors it is usually expressed as the ratio of an output voltage to the input energy expressed in watts, but for detectors in the visible region, for which the older term *sensitivity* persists, a more common unit is the ratio of output current to incident luminous flux (ampere/lumen). It is very important that the spectral distribution of energy in the radiation shall be specified explicitly or implicitly, because all photoelectric detectors have a markedly selective spectral response.

In this survey figures of ultimate sensitivity and responsivity will be quoted wherever possible, but in practice figures which can be compared one with another are very difficult to find. Work now in progress at the British Scientific Instrument Research Association is aimed at resolving this unsatisfactory state of affairs.

Characteristics of photoelectric transducers

Table 1 gives the useful spectral range and region of maximum response for all the main types of transducer now commercially available in this country, together with typical values of responsivity. The values of responsivity are not strictly comparable because the spectral distribution of energy in the sources used for the measurements are not the same in all cases. For the lead salt photocells the spectral sensitivities are so markedly different that a common basis of comparison, related at the same time to their fields of usefulness, is not easy to define. For instance, if a black body radiator at 200 deg C is taken as the source, the lead telluride cell cooled to − 183 deg C has the highest responsivity and lead selenide by far the lowest, but of course the selenide cell would not be used for measurement of total radiation. Values of noise equivalent power for these and other cells are given in Table 2.

Table 1 shows that the photoemissive cells, the photovoltaic cells and the cadmium sulphide and cadmium selenide photoconductors operate mainly in the visible region with limits in the ultra-violet and red or near infra-red regions; the remaining detectors are chiefly useful in the infra-red region, though the photodiodes and phototransistors with maximum sensitivity in the near infra-red are nevertheless used as detectors for visible light. In selecting a photoelectric cell for receiving radiation from a tungsten lamp one should remember that though this is a 'visible' source the peak output lies in the near infra-red. Since present applications of photocells are very largely concerned with visible light those cells which are so used will receive the greater attention in the following sections. As the potentialities of infra-red radiations are realized, applications of infra-red cells will doubtless equal those of visible light cells, in importance if not in numbers.

TABLE 2

PHOTOCELL	NOISE EQUIVALENT POWER, W	CONDITIONS
Lead sulphide	$5{\cdot}5 \times 10^{-11}$	Monochromatic: 2 μ
	5×10^{-9}	Black body: 200 deg C
Lead selenide	$<8{\cdot}5 \times 10^{-9}$	Monochromatic: 4 μ
Lead telluride	$2{\cdot}2 \times 10^{-10}$	Monochromatic: 4 μ
	$<8 \times 10^{-11}$	Black body: 200 deg C
Indium antimonide (photoconductive)	$<4 \times 10^{-9}$	Monochromatic: 6 μ
Indium antimonide	1×10^{-9}	Monochromatic: 6 μ
(photoelectromagnetic)	6×10^{-9}	Black body: 200 deg C

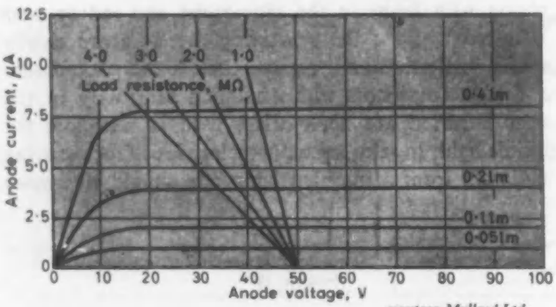
TABLE 1

CLASS	TYPE	WAVELENGTH RANGE, μ	REGION OF PEAK SENSITIVITY, μ	RESPONSIVITY
Photoemissive	Silver-oxygen-caesium	0·2[1] − 1·1	0·65 − 0·85	Vac.: 20–50 μA/lm Gas: 100–150 μA/lm
	Antimony-caesium	0·2[1] − 0·65	0·40 − 0·46	Vac.: 30–80 μA/lm Gas: 75–150 μA/lm
	Bismuth-silver-oxygen-caesium	0·2[1] − 0·75	0·43 − 0·53	Vac.: 20–50 μA/lm Gas: 100–150 μA/lm
Photovoltaic	Selenium (normal)	0·3 − 0·7	0·52 − 0·62	100–500 μA/lm
	(infra-red)	0·3 − 0·9	0·65 − 0·75	100–500 μA/lm
Photoconductive	Cadmium sulphide	0·4 − 0·9	0·5 − 0·7[2]	1 A/lm
	Cadmium selenide	0·2 − 0·8	0·7 − 0·75	1 A/lm
	Lead sulphide	0·5 − 3·4	2 − 2·7	180 μ V/μW[3]
	Lead selenide	1 − 5	2·5 − 3·5	6μV/μW[3]
	Lead telluride	1 − 5·5	4 − 5	650 μV/μW[3]
	Indium antimonide	1 − 7·5	5·5 − 7	(4)
Photodiode	Germanium	0·4 − 2·0	1·4 − 1·8	30 mA/lm
Phototransistor	Germanium	0·5 − 1·7	1·2 − 1·6	300 mA/lm
Photoelectromagnetic	Indium antimonide	1 − 7·5	5·5 − 7	(4)

1. Quartz envelope (lower limit with glass envelope: 0·33 μ)
2. Sharp peak between 0·5 μ and 0·7 μ according to impurity content
3. Black body radiation at 200 deg C
4. Comparable data not available

Photoemissive cells

For precise measurements in the ultra-violet, visible and near infra-red regions of the spectrum, for control mechanisms operated by low-intensity light or by radiation outside the range of more responsive transducers, and in some, but not all, control mechanisms calling for linear response to radiation intensity, the *photoemissive* cell is clearly indicated. (Before *photoelectric cell* became a general term it was rather loosely understood to apply only to the photoemissive cell). This device consists of a sensitized cathode and a collector or anode; the electrodes are mounted in a quartz or glass envelope which is either highly evacuated or filled with



courtesy Mullard Ltd

Fig. 1 Anode-current/anode-voltage characteristics of a typical vacuum photoemissive cell (Mullard 90CV) for various levels of illumination. Load lines are drawn for a supply voltage of 50 V

an inert gas such as argon. (Sometimes the cathode is deposited on the inside surface of the envelope.) In the simplest mode of operation a direct voltage is applied between anode and cathode with a load resistance (typically 1 megohm) in series with the cell. When the cathode is illuminated photoelectrons are emitted and are collected at the anode, causing a small current (of the order of microamps) to flow in the external circuit. The p.d. appearing across the load resistance is amplified by either an a.c. or a stable d.c. amplifier, depending on whether the radiation is 'chopped' or not; alternatively the current is measured directly by a microammeter. In a vacuum cell, provided that the anode voltage is sufficiently high, all the photoelectrons will be collected, and the cell is then said to be saturated. At voltages above the saturation voltage the anode current is nearly, but not quite, independent of the voltage. The voltage necessary for saturation depends, of course, on the intensity of illumination; the working voltage is usually between 50 V and 100 V. The operating conditions of the gasfilled cell are rather different from those of the vacuum cell, because although the cell saturates in the same way as does the vacuum cell, increasing the applied voltage to a value a little above the saturation voltage causes ionization of the gas. The primary photocurrent is thus amplified by a factor (the *gas amplification factor*) which depends on the anode voltage. A limit to the anode voltage (and hence to the amplification) is set by the increase of secondary emission at the cathode; this leads to instability and, incidentally, to permanent damage of the sensitized surface of the cathode. The maximum amplification obtainable in a gasfilled cell is about 10, with an anode voltage of 90 V.

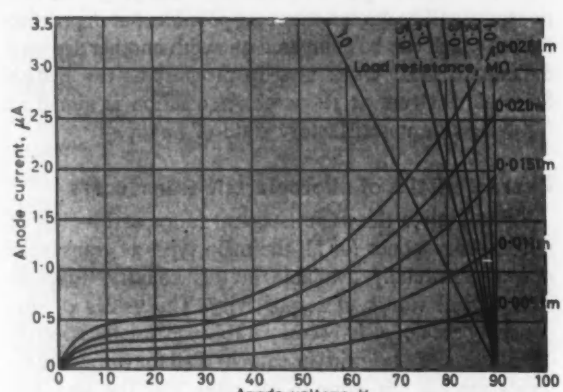
Response characteristics

Curves giving the relationship between photocurrent and applied voltage for various values of light flux are shown in Figs. 1 and 2. These are for vacuum and gasfilled cells of the same cathode coating material (silver-oxygen-caesium) and size. It will be seen that the vacuum cell is linear in its response to varying light flux so long as the working condition (indicated by intersection of the load line with the appropriate curve) remains in the saturated region of the characteristic.

In a gasfilled cell, the intercepts on the load line (Fig. 2) show that, while the output of the cell is much greater than that of the vacuum cell, the response is not linear.

The spectral response of photoemissive cells depends on the cathode coating. The three coatings in common use are: (1) antimony-caesium (Sb–Cs) for ultra-violet and blue light; (2) silver-oxygen-caesium (Ag-O-Cs) for red and near infra-red; and (3) bismuth-silver-oxygen-caesium (Bi–Ag–O–Cs) for response approximating to that of the human eye.

Unfortunately if the spectrum from blue to infra-red has to be scanned one must change over from the



courtesy Mullard Ltd

Fig. 2 The relatively high responsivity—particularly at low illumination—of a gasfilled photoemissive cell is shown by these characteristics of the Mullard 90CG, the same photocell as that of Fig. 1 but filled with argon. Note that a higher working voltage is needed to obtain the advantages of gas amplification

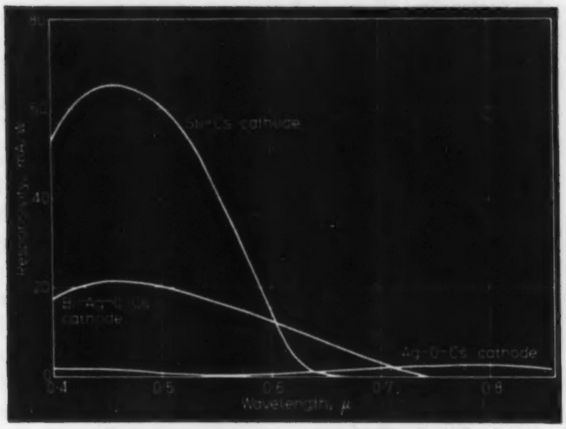
antimony-caesium to the silver-oxygen-caesium cathode at about 0·65 μ; moreover the latter cathode is much less sensitive to monochromatic light than is the blue-sensitive cathode over most of its range. Fig. 3 illustrates the relative spectral responsivities of the three cathodes.

There is a notable difference in the response of vacuum and gasfilled photocells when the incident light intensity varies (or is chopped) at high frequencies. While the output of the vacuum cell is independent of frequency up to 10 Mc/s, the response of the gasfilled cell begins to fall appreciably above 10 kc/s.

The chief advantages of the vacuum photoemissive cell are the linear relationship between photocurrent and intensity of radiation, the extremely low dark current

(current under the condition of no illumination), the wide range of spectral sensitivity and the linear frequency response. The fact that the output is in the form of a varying voltage across a high impedance makes this type of photocell ideal for coupling to a valve amplifier, so that low light intensities are acceptable.

Photoemissive cells are commonly employed for matching colours and for monitoring whiteness of paper and similar materials; two photoemissive cells or photomultipliers are used in a bridge circuit and departures from a standard are indicated by the off-balance current of the bridge. A similar arrangement is used in detectors for various organic vapours such as carbon disulphide



courtesy Rank-Cintel Ltd

Fig. 3 Spectral response curves for the three principal types of photocathode

and benzene, which have characteristic absorption bands in the ultra-violet. The gasfilled cell, with its high responsivity, is valuable in sound reproduction from ciné-film and in 'on-off' control at low intensities or small differences in intensity. But such cells are not used for precise photometric purposes because the cell current under steady illumination shows some instability. To provide a modest degree of amplification without the instability inherent in the gasfilled cell, single-stage photomultiplier cells are now on the market.

Both vacuum and gasfilled cells are available in a variety of forms to suit special purposes, particularly where two separate cathodes with or without separate anodes are required. The volatile nature of the sensitized cathode coating sets an upper limit to the ambient temperature to which these cells may safely be exposed: the limit for Ag–O–Cs cathodes is 100 deg C and for Sb–Cs cathodes 50–70 deg C. Changes in temperature have no effect on sensitivity or spectral response, but the dark current increases with temperature; when very low dark current is essential the cell must be cooled.

Variability of characteristics

The sensitivity (responsivity) of photoemissive cells varies from specimen to specimen over a comparatively wide range. The figure for sensitivity quoted by the maker is usually a minimum value and sensitivities up to at least three times the quoted value may occur. As the cell ages its sensitivity tends to fall especially if it is run at maximum rating, though the vacuum cell is inherently much more stable in this respect than the gasfilled cell. Short term fatigue is also observed at very high flux intensities, and a drift in output (either an increase or a decrease) may occur at normal levels of illumination. Recovery takes place in darkness but at a much slower rate than that of the drift. Permanent and temporary changes in sensitivity due to high intensities are avoided by keeping the output down to about one-tenth of the maximum rating for Sb–Cs and Bi–Ag–O–Cs cathodes and to one-fifth of that for Ag–O–Cs cathodes.

The spectral response also shows variations among samples having the same cathode coating: these variations in the shape of response curve and in wavelength of peak response tend to be greater with the Ag–O–Cs cathode than with the Sb–Cs cathode.

In making repeated photometric measurements it is important that the same area of the cathode is illuminated each time, since individual cells show some variation of sensitivity over the cathode. Special cells are available for high-precision measurements; they have improved linearity of response and a dark current as low as 5 $\mu\mu$A.

The anode-current/anode-voltage curve often does not represent a smoothly varying function but instead a sudden increase in anode current may occur. This will not give rise to an error in measurement provided that the cell current remains saturated at all values of the light flux; there is some danger, however, that this condition will not be maintained at maximum intensity if a very high load resistance is in circuit.

Photomultipliers

Instead of amplifying the very small signal from a photoelectric cell with a separate amplifier the photocurrent from the cell cathode may be amplified by a series of secondary emission processes within the cell. The primary electrons are accelerated to a collector (dynode) of which the surface is treated in such a way as to encourage the emission of secondary electrons. The impact of each primary electron releases several secondary electrons: these secondary electrons are accelerated to a second dynode where again secondary emission gives an amplification of current. With 11 dynodes the total gain is of the order of 10^6. The accelerating voltage is usually about 100 V per stage so that a stable high voltage source (1–2 kV) is required.

The photomultiplier is clearly of great value when very weak radiation has to be measured. Not only is a high gain achieved in a very compact piece of apparatus but the noise associated with this system is very much lower than that of a thermionic amplifier; the gain which can usefully by employed in external amplifiers is limited by noise from sources such as the valves and resistors.

A second major advantage of the photomultiplier is that a steady or slowly varying photocurrent is amplified without any difficulty. With a simple photoemissive cell either the incident radiation has to be 'chopped' to give an output which can be amplified with a conventional

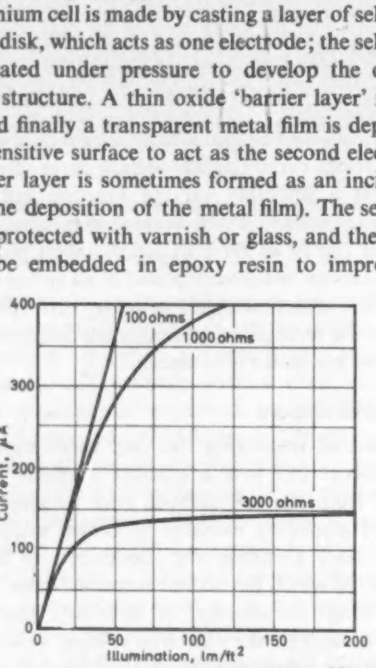
a.c. amplifier, or the problem of stabilizing a d.c. amplifier has to be overcome. At the other end of the frequency scale we find response times short enough to resolve light flashes with intervals of 10^{-4} microsec. This fast response coupled with very high sensitivity has made possible the scintillation counter for the measurement of ionizing radiations.

The characteristics and limitations of the cathode are of course the same in photomultipliers as in the corresponding (single-stage) photoelectric cells. It is possible to construct a photomultiplier with the infra-red sensitive Ag–O–Cs cathode; but the Sb–Cs or the Bi–Ag–O–Cs cathode is almost always used for commercial cells.

Photovoltaic cells

Other names for the *photovoltaic* cell are: *barrier-layer* cell, *photo e.m.f.* cell and (according to the composition of the sensitive layer) *copper oxide* or *selenium* cell.

The selenium cell is made by casting a layer of selenium on an iron disk, which acts as one electrode; the selenium is then heated under pressure to develop the correct crystalline structure. A thin oxide 'barrier layer' is next formed and finally a transparent metal film is deposited over the sensitive surface to act as the second electrode. (The barrier layer is sometimes formed as an incidental result of the deposition of the metal film). The sensitive surface is protected with varnish or glass, and the whole cell may be embedded in epoxy resin to improve its



courtesy Megatron Ltd

Fig. 4 The external resistance affects the response of a photovoltaic cell. These characteristics refer to a Megatron Type B

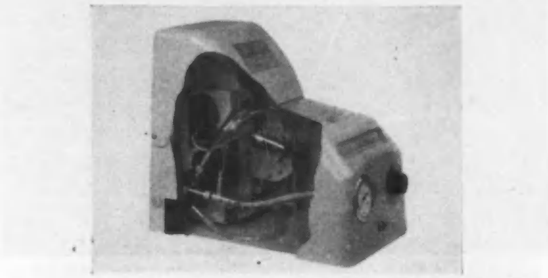
durability. The incidence of light on the sensitive surface causes a potential difference to be developed across the barrier layer and, if the external circuit is closed, a current flows. Copper oxide cells are similarly constructed but their base is of copper instead of selenium or iron. In Great Britain selenium cells have largely replaced them.

The current/illumination characteristics of photovoltaic cells of a given type vary considerably with the diameter of the cell and with the external resistance. A typical set of response curves for a circular cell of 39 mm diameter is given in Fig. 4. The external circuit resistance influences the shape of the characteristic curve because the barrier layer acts as an internal shunt resistance whose value is approximately inversely proportional to the illumination. It is a general rule that for linear response the external load resistance must be as low as possible and conversely that for an approximately logarithmic response it must be fairly high.

Somewhat like the human eye

The spectral response of cells other than those specifically designed for sensitivity in the near infra-red superficially resembles that of the human eye, having a peak in the yellow-green and falling to zero in the near ultraviolet and the extreme red end of the visible spectrum; the sensitivity in the blue and blue-green regions is in fact very much higher than that of the eye and where a photometric value comparable with the visual stimulus is required the use of an 'eye-filter' is essential. Owing to the variability of spectral response characteristics, cell and filter must be matched for accurate correction.

The small separation and comparatively large area of the electrodes result in a rather high self-capacitance (e.g. 0·5 μF) so that for a cell of normal size frequency



courtesy Evans Electroselenium Ltd

Fig. 5 Photovoltaic cells find useful application in flame photometers. In this cut-away view of a typical instrument the photocell is visible on the side of the flame chamber, above the sample intake and atomizer

response falls off severely in the audio-frequency range unless the load resistance is very low. For sound reproduction, cells of very small area are made.

The photovoltaic cell may be regarded as the maid-of-all-work among photoelectric transducers. It is fairly robust in construction, is simple to use because it requires no external source of current or voltage, and is sufficiently sensitive for a great number of applications without requiring amplification of the output.

Indeed, amplification is not easily applied to the output of photovoltaic cells. The photocell current is not normally high enough to operate a robust electromagnetic relay. A light relay can be employed to enable the photocell to act as a counter or as an on-off position indicator but the photovoltaic cell finds its most useful applications in instrumentation; here it provides the measuring element in such instruments as exposure meters, colorimeters, and flame photometers (Fig. 5).

Limitations

The upper temperature limit, above which the cell may be permanently damaged, is between 45 and 60 deg C.

Characteristics are variable from cell to cell but manufacturers can always select cells to perform within close tolerances for specified illumination intensities and load resistances.

Photoconductor cells

Although there are many materials which show a variation of conductivity when irradiated and although selenium and thallium sulphide photoconductive cells have been known and used for many years, the only photoconductive cells in commercial production in this country at the present time are those based on lead sulphide, lead selenide, lead telluride, cadmium sulphide, cadmium selenide and indium antimonide. Of these, only the cadmium sulphide and cadmium selenide photocells are highly sensitive to visible light.

Cadmium sulphide and selenide cells

The cadmium salt cells are remarkable for the high currents which they will pass when illuminated at high intensity. For instance, the current through a cadmium sulphide cell under an applied voltage of 10 V may be as high as 40 mA at an illumination level of 100 lm/ft².

The construction and maximum power dissipation of cadmium sulphide and selenide cells vary considerably from cell to cell. As would be expected, the maximum dissipation is determined by the area of the receiving surface. The rate of variation of current with illumination is not constant: it depends on the intensity and on the applied voltage. The highest responsivity occurs at low illumination. It is, in fact, hardly possible to compare cells of different makes on a general basis; one must know in each case how much energy is available for concentration on the receiving surface, which may be as small as 0·2 mm² or as large as 2·9 cm².

As the intensity of illumination falls the applied voltage may be raised in order to increase the responsivity, up to the prescribed limit of power dissipation. Fig. 6 shows the range of operating conditions and current outputs for a cadmium sulphide cell (receiving area 2·9 cm²). The maximum permissible dissipation falls rapidly as the ambient temperature rises, and the decay of current when the illumination is cut off is slow (of the order of 100 sec). This type of transducer is eminently suitable for the direct operation of low-current relays. Many opportunities exist in production control for optical monitoring of dimension or position, a variation in which can be made to change the amount of light falling on a single photocell or a pair of cells. Thus sag or tension in wires, threads and belts can be kept within close limits by arranging for interception of two light beams falling on a pair of cells, one above and one below the correct level of an indicator riding on the wire or belt. Even temperature can be controlled fairly closely by monitoring the level of a mercury column; the rising column cuts off the light beam falling on a photocell and so operates a relay to switch on a heating current. It is not particularly suitable for the measurement of chopped radiation, or radiation of rapidly varying intensity.

Photodiodes and phototransistors

When radiation of wavelengths between 0·5 μ and 1·4 μ is absorbed near the alloy junction of a p–n germanium diode the potential barrier at the junction is lowered. The current which passes through the diode when a potential difference is applied across it thus varies with the incident radiant flux. As the name implies, the current/voltage characteristic for a given level of illumination is similar to that of a thermionic diode at a fixed cathode temperature: with increasing applied voltage the current rises rapidly to a 'saturation' value at about 1 V. This is not true saturation since raising the voltage above this value does increase the current, at a rate depending on the intensity of illumination, but the increase is comparatively slight. The 'saturation' value is nearly proportional to illumination. Permissible currents are of the order of milliamperes (2·5 mA max.)

It is a logical step from the photodiode to the p–n–p phototransistor, in which the amplifying action of the transistor is applied to the photocurrent. About 10 times the responsivity of the diode is achieved in this way, though on account of a temperature effect the permissible power dissipation is no higher. Maximum current is 10 mA.

In considering applications of photodiodes and phototransistors two peculiarities must be taken into account, a dark current which is not negligible and a marked dependence of both light and dark currents on temperature. For instance the dark current in a photodiode at 50 deg C is equal to the current due to a flux of 15 millilumens (illumination: 180 lm/ft², approx.) at 20 deg C; it is also 20 times the dark current at 20 deg C. Mainly for these reasons, the use of alloy junction photocells is at present confined to counting and relay operation. The maximum operating frequency is 50 kc/s for the photodiode and 3 kc/s for the phototransistor. Their very small size is a great asset: the STC photodiode Type PG40B is in the form of a cylinder 0·080 in. diameter with a glass window in one end to admit radiation to the element, which has an area of 0·03 in. × 0·02 in. The Mullard OCP 71 phototransistor is enclosed in a glass bulb 5·9 mm in diameter and 15 mm in length; the light may be incident along the axis of the bulb or, preferably, perpendicular to the axis.

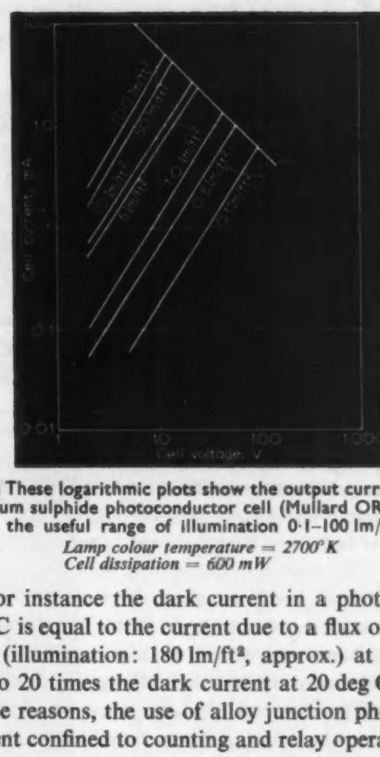


Fig. 6 These logarithmic plots show the output currents of a cadmium sulphide photoconductor cell (Mullard ORP90) for the useful range of illumination 0·1–100 lm/ft²

Lamp colour temperature = 2700°K
Cell dissipation = 600 mW

In addition to their optical properties, these devices possess the electrical characteristics common to all junction diodes or transistors and the principles of circuit design are correspondingly applicable.

A typical application of these photodiodes and phototransistors is to the high-speed counting of the interference fringes now being used in accurate forms of machine tool control. They are also very suitable for operating PO-type relays.

Phototransducers for the infra-red

Lead sulphide, selenide and telluride photoconductors

For infra-red detection the lead salt photoconductive cells provide a variety of characteristics. The most responsive is the lead sulphide cell and since it has maximum spectral sensitivity in the range 1–3 μ it is a suitable transducer for low-temperature radiation pyrometry. The lead selenide cell has a much lower response at the short infra-red wavelengths but remains sensitive up to 5 μ at room temperature; it is a useful detector for infra-red spectrophotometers. For a complete scan of radiation over the range 1–6 μ the very sensitive lead telluride cell is available but to obtain the highest possible values of signal/noise ratio this cell must be cooled to the temperature of liquid oxygen.

The three types of lead salt cell are similar in construction. The photoconducting film is deposited on the inside of a thin window which closes one end of an evacuated glass envelope; the receiving area is defined by the electrodes. In the lead sulphide cell the area is about 6×6 mm^2; it is smaller for selenide and telluride cells.

Photoconductor cells are normally connected in series with a non-reactive resistor of 1 megohm and a direct voltage source of up to 250 V; the signal appears as a potential difference across the resistor. The signal current varies linearly with the voltage for a given intensity of incident radiation.

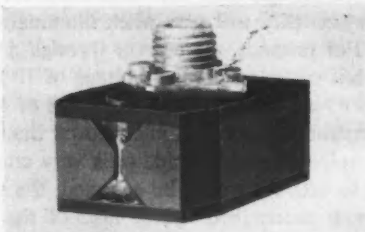
In order to eliminate the effect of stray radiation (a very important consideration in infra-red work, where, for instance, changes in ambient temperature can give a spurious signal) and also to simplify signal amplification, the incident radiation is interrupted (chopped) at a fixed frequency. The photoconductor cells have response times of the order of 1–100 microsec so that the chopping frequency may be fairly high (800 c/s is a common frequency). With such short response times the cells are able to follow very fast transient changes in temperature.

The variations in cell characteristics which occur in manufacture, the fatigue effects (markedly affected by ambient temperature) and the tendency for change of sensitivity with age make it necessary to use these cells as comparators when photometric accuracy is required.

Indium antimonide cells

Indium antimonide is a semiconductor compound which shows photoconductivity over a wide region in the intermediate infra-red, with a time-constant as short as 1 microsec. The receiving area of the Mullard cell ORP10 is in the form of a strip 6 mm long and 0·5 mm wide. The photoconductor itself is attached to a substantial mount which tends to stabilize its temperature; this is necessary because photoconductivity in semiconductors varies with the temperature. A great advantage of this photocell is that it needs no protecting envelope, so that there is no window problem.

By mounting a sliver of indium antimonide between the poles of a permanent magnet, the pairs of charge carriers generated by absorption of infra-red radiation can be separated and made to diffuse to opposite ends of the sliver. A p.d. is thus set up between electrodes at each end, and the cell behaves as a photovoltaic cell. This *photoelectromagnetic* cell (Plessey type PC21, Fig. 7)



courtesy Plessey Ltd

Fig. 7 A sliver of the semiconducting indium antimonide is fixed between the poles of a permanent magnet in this photoelectromagnetic cell (Plessey PC21). The dimensions of the cell are approximately 1 in. $\times$ $1\frac{1}{2}$ in. $\times$ $\frac{5}{16}$ in. (excluding connector socket).

has a sensitivity similar to that of the indium antimonide photoconductive cell. The photoconductive cell has the advantage of very small size; the photoelectromagnetic cell has a greater bulk due to the magnet (which carries with it the danger of damage by pick-up of magnetic particles) but generates a signal voltage without any external power supply.

The maximum operating temperature for indium antimonide photocells is 70 deg C. This is rather higher than that recommended for the lead sulphide cell (60 deg C) or the lead selenide cell (40 deg C). As has already been indicated, the main industrial uses of the infra-red photoconductor cells are in pyrometry and infra-red spectroscopy, and the number of instruments for these purposes will undoubtedly increase considerably in the near future. The detection and following of hot bodies also has great military importance and the very high sensitivity of these cells is certainly being exploited in that field.

Photocells for the future

Advances seem to be taking place mainly in the field of semiconductor photocells. The cadmium sulphide, cadmium selenide, and indium antimonide cells are still quite new and will probably be developed to higher sensitivities, wider spectral ranges and faster response. A gold-doped germanium infra-red photoconductor cell, recently announced in America, is claimed to be sensitive at wavelengths up to 10 μ with a response time of 0·2 microsec. These advances are based on fundamental research on the properties of semiconductors but much remains to be done on the technical side before commercial production can take full advantage of the possibilities opened up by research.

CONTROL IN ACTION

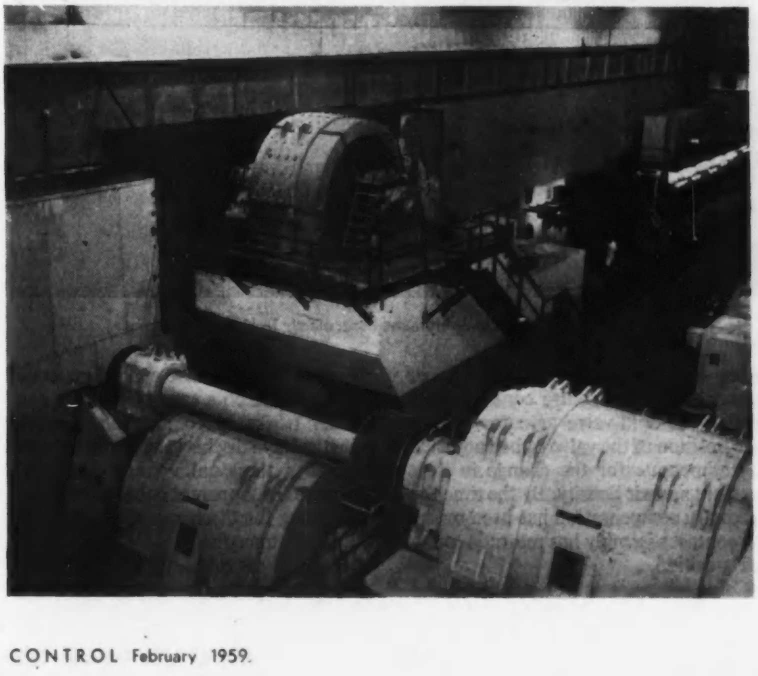
Steel Company of Wales' new universal slabbing mill rolls 60,000 tons of ingots a week

Fig. 1 Universal mill pulpit at Abbey Works. The rollerman is seated at the centre rear and the assistant rollerman on the left. The third member of the team is concerned with ingot quality. Note simultaneous operation of hand and foot controllers

Universal mill at Port Talbot

A NEW UNIVERSAL MILL HAS REPLACED the original slabbing mill at the Steel Co of Wales' Abbey Works, as part of the company's long term plan for increased production. The changeover, which in itself was a triumph of organization, took 10 days from the removal of the old mill to the entry of the first ingot into the new universal. The major difference between the old and new machines is that the universal mill is equipped with vertical rolls, as well as the conventional horizontal rolls, so that 'edging' can be done without turning the slab. This, of course, means that ingots can be rolled into slabs at a faster rate and, in fact, the capacity is expected to be in excess of 60,000 tons a week—12,000 tons higher than the capacity of the old slabbing mill.

Fig. 2 The motor room for the universal. The main drive for the vertical rolls is on the raised platform, and the horizontal drive motor in the right foreground



Pulpit control

The mill pulpit or control room (Fig. 1) is staffed by two rollermen and a member of the metallurgical department who keeps an eye on ingot quality. Rollerman and assistant rollerman, who are seated side-by-side in aircraft type seats, face Selsyn indicators which provide information on the horizontal and vertical rolls. Both operators control the process using hand levers—both hands simultaneously—and foot pedals, and a Marconi TV monitor enables them to view an ingot once it is out of direct view behind the vertical rolls. The rollerman's left hand operates two levers which control the ingoing and outgoing tables, i.e. approach and runout; his feet operate the main drive controllers, i.e. the feed rolls, forward and reverse, for both the vertical and horizontal mills; his right hand controls horizontal screwdown, which is manual on this mill and not automatic as might be expected for a new installation. The assistant rollerman's left hand controls the East manipulator and the approach tables; his left foot may control the scale

table, although normally this is done by the operator in the buggy pulpit; and his right foot, the tilt fingers which turn the ingot over for a single pass (this is necessary once only, the vertical rolls carrying out 'edging' thenceforth). His right hand controls the West manipulator and screwdown (more correctly screwin) of the vertical or 'edging' rolls.

Voltage control system

The mill itself is by Davy United and the majority of the electrical equipment and the drive motors by English Electric. Control is fairly conventional, being much the same as that of the slabbing and blooming mill at the Consett Iron Company's County Durham works*. The Consett mill has horizontal rolls only, but basically the system is much the same. The motor room for the universal mill is shown in Fig. 2, the drive motor for the vertical rolls being at centre rear, and the horizontal rolls motor in the right foreground.

A voltage control system is employed in which a reference is set up by the foot controller in the pulpit. This reference voltage is balanced by a corresponding generator output which sets the mill speed up to base on the main motors. Higher speed increments are obtained by a further movement of the foot pedal which weakens the field of the main drive motors. The control scheme includes full current limit control and a balancing system to vary the top and bottom roll speeds with respect to each other, in order to assist in the rolling action. A facility peculiar to the universal mill is that there is an extra control for tieing-in the speed of the vertical rolls with that of the horizontal rolls. This enables all faces of the ingot to be rolled simultaneously.

High-speed ingot delivery

The mill must be fed from the 28 soaking pits at a rate which allows it to develop its full potential. At present, a 100-ton ingot buggy proceeds to a pit, on command from the buggy pulpit, obtains an ingot and delivers it to the mill receiving table. As two ingots are normally processed simultaneously, there is a slight lag between operations. In order to overcome this lag, trials are now proceeding of a new system which entails the use of a shuttle car on the same track as the ingot buggy. Basically, the idea is to use the buggy to obtain the ingots, as before, but to transfer them to a shuttle car which feeds the mill with two ingots at a time.

As both vehicles will be running on the same track at speeds around 1000 ft/min, they must close each other at very high speeds for the transfer of ingots. Control is, therefore, extremely complex. The buggy is electrically powered using a conductor rail, and the shuttle car is powered by cables with winches at both ends of the run. The buggy tows a cable from a winch whose gearbox operates a torquemeter feeding a potentiometer. Potentiometers are also attached to the shuttle car winches. The operation of both vehicles is synchronized with the aid of signals from these potentiometers.

*Mathieson, R.: 'Electric Drives at Consett' CONTROL Nov 1958, p 235

CONTROL IN ACTION

Cabin air control in Vickers Vanguard

Conditioned air for up to 139 passengers

IN KEEPING WITH ITS MODERN DESIGN the Vickers *Vanguard* carries the latest equipment by Normalair Ltd for regulating the air supply to passenger and crew cabins, and for controlling the pressure in the cabins.

Fig. 2 Modern equipment controls air in *Vanguard*

Flow control

The cabin air supply is provided by blowers driven by the aircraft engines, and mass flow is controlled by the electropneumatic system of Fig. 2. In operation, the metering head senses duct static and venturi static pressures. When the correct mass flow is being delivered, the differential pressure across the mass flow controller diaphragm is such that the contact assembly in the controller is held in the 'off' position. Any variation in flow will cause a differential pressure change, and consequent movement of the diaphragm will close the centre contact to one or other of the outer contacts. This completes the appropriate spill-valve actuator circuit, the position of the valve is adjusted to re-establish the correct flow, and the contact assembly returns to the 'off' position.

Pressure control

Any change in duct pressure, and thus in air density, results in extension or compression of the capsule stack in the mass flow controller. This, in turn, causes the outer contacts to pivot, until one or other touches the centre contact, completing the spill-valve actuator circuit. The position of the valve is then adjusted to compensate for the change in duct pressure and air density. By the time the necessary compensation has been made, the contact assembly has returned to the 'off' position.

Cabin pressure is controlled by the Normalair multi-valve control system of Fig. 3, in which a type H pressure controller works in conjunction with six identical civil discharge valves in parallel. Together, these units control the cabin pressure (i.e. apparent cabin altitude) by regulating the discharge of air from the cabin to atmosphere.

Control of cabin pressure is completely automatic, cabin altitude chang-

ng smoothly as aircraft altitude varies. The rate of change of cabin altitude is automatically restricted to an acceptable figure and, except in an emergency, all the aircrew have to do is select the height at which control is to begin or end. Control can, if required, begin on take-off, since the airport altitude selector allows for both the height of the airport above or below sea-level, and the prevailing airport barometric pressure. The parallel arrangement of the discharge valves has reduced back-pressure to a minimum and consequently the initiation of control is smooth, so much so that it is said to be imperceptible to the cabin occupants.

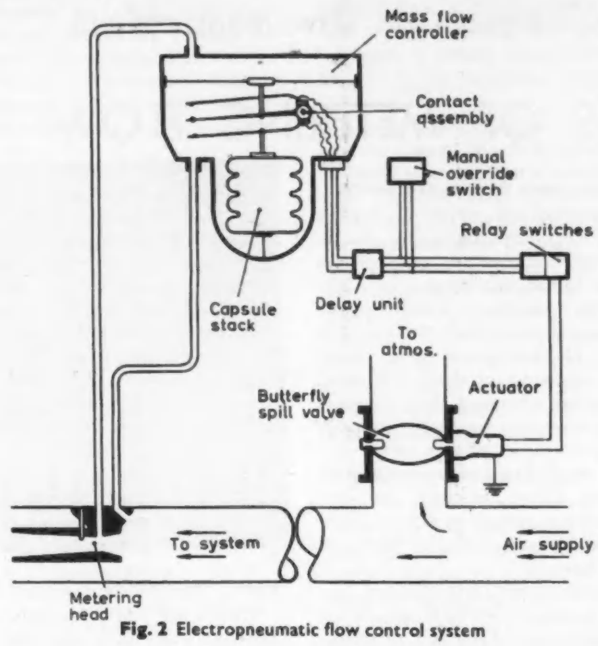


Fig. 2 Electropneumatic flow control system

The discharge valves also function as safety valves, to prevent cabin pressure exceeding the maximum permitted figure, and as inwards relief valves, to prevent cabin pressure falling below atmospheric by more than an acceptable amount.

Before take-off, the height at which control is to begin is selected on the airport altitude selector. When the aircraft engines are started, suction is applied by the jet pumps to both the pressure controller and the discharge valves. The effect of this is to place the pressure controller mechanism in a controlling position, and to hold the discharge valves open.

Assuming control is not starting on take-off, cabin air is able to bleed to atmosphere through the pressure controller and airport altitude selector. As the aircraft climbs away after take-off, this bleed gradually diminishes, owing to the capsule stack in the selector extending as atmospheric pressure falls. By the time the selected starting height is reached, the bleed has ceased completely. The pressure controller is now able to begin controlling, and a signal is passed to the discharge valves, bringing them into their controlling position.

Whilst the aircraft is climbing, the pressure controller and discharge valves regulate the discharge of air from the cabin to atmosphere in such a way that the differential pressure between cabin and atmosphere gradually increases, cabin pressure falling less quickly than atmospheric. By the time the aircraft reaches its normal operating altitude, the differential pressure has reached the maximum designed value for the aircraft. If the aircraft goes on climbing, the differential pressure is automatically maintained at this value by the action of a differential pressure control mechanism in the pressure controller.

Fail-safe characteristics

Should two of the discharge valves fail together in the open position, the position of the remaining valves is automatically adjusted to compensate, full pressure control being maintained at normal aircraft operating altitudes. Should two fail in the closed position, the remaining valves can pass sufficient air to prevent an unacceptable rise in cabin pressure.

If, for any reason, the cabin pressure rises to the maximum permitted figure, the discharge valves function automatically as safety valves to prevent any further increase. In the event of two valves failing in the closed position under these circumstances, the remaining valves can together pass sufficient air to limit cabin pressure to the maximum permitted value. Should cabin pressure fall below atmospheric, the discharge valves operate automatically as inwards relief valves, to limit the negative differential pressure to an acceptable figure. In the remote event of failure of the pressure controller, the integral emergency pressure controller automatically assumes control, maintaining the apparent cabin altitude at a safe, predetermined level.

Cabin pressure can be reduced, in emergency, in either of two ways. If time allows, a suitable cabin altitude can be selected on the airport altitude selector, the cabin altitude then changing at a controlled rate. On the other hand, the reduction can, if necessary, be made rapidly by opening the mechanically-operated dump valve.

Before descent for landing, the height at which control is to end is selected on the airport altitude selector. As height is lost, the differential pressure between cabin and atmosphere gradually decreases, until, at the selected height, the bleed of cabin air to atmosphere through the selector is re-established, and pressure control ends.

The complete system weighs 53 lb.

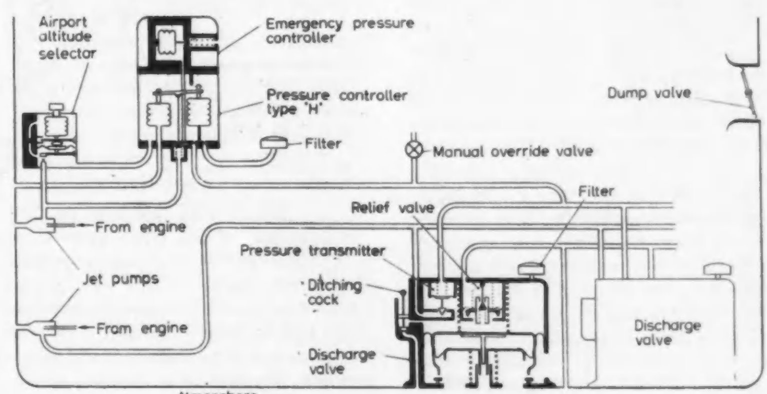


Fig. 3 Cabin pressure control system

A 72 in. magnetic flowmeter used for sewage

A Special Correspondent reports on the recent SIT symposium on flow measurement

NEW METHODS OF METERING FLOW

A LARGE AUDIENCE ATTENDED A LONDON meeting of the Society of Instrument Technology on 27th January to hear four papers on flow measurement. The Chairman, Mr R. S. Medlock, emphasized that problems of flow measurement represented a continual challenge: it was encouraging to learn that modern developments were keeping pace with requirements by providing new solutions.

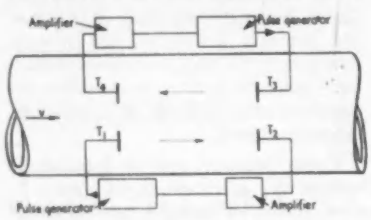


Fig. 1 In this oscillating-loop ultrasonic flowmeter arrivals of pulses at T_2 and T_4 trigger further pulses at T_1 and T_3

The papers make no attempt to treat flow measurement comprehensively but describe specialized methods of current interest. They share little common ground. A paper on 'The Ultrasonic Flowmeter' is essentially a survey of fundamental techniques on which suitable designs can be based. Another on 'Mass Flowmeters' is a generalized account of developments in this type of meter. The other two papers, on 'The Magnetic Flowmeter' and the 'Electronic Propeller Flowmeter' treat, in more detail, commercially available instruments. The discussion at the meeting raised a few additional topics and amplified some of the authors' remarks.

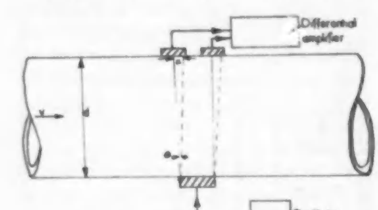


Fig. 2 The beam deflexion ultrasonic flowmeter is suitable for comparatively high flow rates when θ becomes measurable

Ultrasonics help flow measurement

In presenting his review of possible methods using ultrasonics, Mr R. E. Fischbacher said that the problem was essentially to use the change in an ultrasonic signal's velocity in a liquid caused by the liquid flow in relation to the signal's direction of propagation. The sound velocities concerned are about 1500 m/sec, while commercially used flow velocities are about 1·5 m/sec; so clearly elaborate measuring techniques must be used.

Ideally an ultrasonic meter demands no obstruction within the pipe, nor any working parts to corrode or clog; it should be suitable for slurries, viscous fluids and pulsating flows.

The signal transit time between two points in a pipe containing flowing liquid is of significance only if it can be related to the corresponding time with no flow. Measurement of the latter time is not practicable, and so the most convenient reference is the transit time for a similar signal transmitted in the opposite direction. Thus each of the two locations in the pipe is equipped with a transmitting and receiving unit. The signal may be a pair of continuous waves, the phase difference being a measure of the relative delay in the two directions. The chosen frequency of this signal is a compromise between several effects, but ultrasonic meters can measure velocities as low as 2 m/sec full scale.

Alternatively the signal may be pulsed, the receipt of each pulse initiating the transmission of the succeeding one (Fig. 1). The relative frequency of the resultant signals in each direction is then a measure of the flow. Owing to limitations in the accurate measurement of l.f. beats between two h.f. systems, such devices will not measure flow velocities below 15 m/sec.

A third method is the cross beam deflexion system (Fig. 2). The beam is at right angles to the pipe's axis and the deflexion of the beam by the fluid is a measure of the flow. Since the effect is very small, it is suitable only for high velocities.

In these systems two important considerations are the similarity of the two transmission paths and correction for the signal velocity in stationary fluid. Fischbacher discussed also the practical location of the transducer systems and the influence of velocity profile on performance.

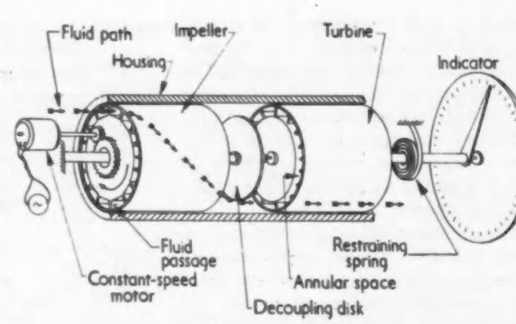
Measuring mass flow

True mass flowmeters were first developed some years ago for aircraft fuel. Some of these have been applied industrially, but here the demand is limited to gas flow and is largely satisfied by conventional volume flowmeters compensated for temperature and pressure.

Mr P. Scanes describes in his paper a number of true mass meters including some designs of primarily theoretical or historical interest. Later designs are generally mechanically complex since they all utilize the radial acceleration of the flowing stream as the fundamental parameter. The Li meter, for example, uses the torque produced in a rotating tube dividing the flow into two paths at right angles to the normal flow axis, as a measure of mass flow independent of fluid density.

In the General Electric mass meter (Fig. 3) an impeller is driven at about 60 rev/min in the flowing stream; downstream

Fig. 3 The General Electric mass flowmeter measures the torque needed to remove a constant swirl velocity



Acknowledgments

Figs. 1-4 are reproduced by courtesy of the Society of Instrument Technology; Fig. 5 by courtesy of Foxboro-Yoxall; and Fig. 6 by courtesy of Firth Cleveland Instruments.

the torque transmitted by the swirling flow to a turbine unit is measured. Intermediate baffles reduce any viscous drag effects. The Bendix meter operates by measuring the torque required to drive an impeller rotating in the stream. Such meters have rangeabilities of 10-20 : 1.

A second class of meters described by Mr Scanes are standard differential measuring instruments in which appropriate correction can be provided for pressure and temperature. The output signals from normal differential head meters, Bourdon pressure gauges, and appropriate temperature measuring equipment are combined pneumatically or electrically. Fig. 4 shows a general indication of a typical electrical bridge system for doing this. Where necessary, it can provide for the square root terms and departures from ideal gas behaviour. Another system uses differential transformers operated by the temperature, pressure and differential pressure units.

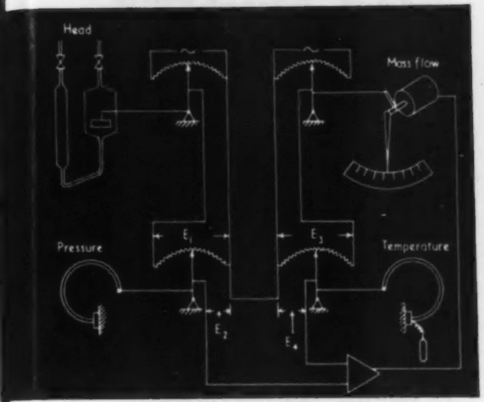


Fig. 4 Differential meters can be fitted with electrical computation of pressure and temperature corrections to give mass flow

Old principle—new realization

The magnetic flowmeter represents the practical realization of an old principle, made possible by the development of suitable electronic techniques. In their paper Mr B. W. Balls and Mr K. J. Brown give a fascinating account of its evolution. The flow of a conducting solution (minimum conductivity 50-100 μmho/cm in practice) in a uniform magnetic field created by a.c. coils induces a voltage directly proportional to the average velocity across the pipe cross-section.

The tube is normally stainless steel with an insulating lining of neoprene, Kel F or similar material, but non-metallic tubes (e.g. plastic) may be used. Two electrodes of stainless steel or platinum are mounted flush in the tube wall to detect the e.m.f. The normal output is about 3 mV at a velocity of 5 ft/sec. Two forms of measurement system are described: one with a differential transformer, and one with a solid slide wire and current transformer for use where the mains frequency may vary. Sizes range from 1/10 in. diameter tubes up to 72 in. (See photograph on opposite page). Accuracies are $\pm$ 1% with a linear rangeability of 100 : 1.

Balls and Brown discuss limitations arising from the requirements for lead length, fluid conductivity, precautions against scaling liquids, etc. The normal fluid temperature limitation is dependent on the linings; it is approximately 230 deg F with a Kel F lining. The meter gives inherently a volume measurement, which must be density corrected if mass flow rates are needed.

Because of the materials of construction and the inherent clear bore, applications of magnetic flowmeters are potentially numerous. They are ideally suited for viscous or corrosive liquors, slurries and other such products under turbulent, laminar or pulsating flow conditions. The magnetic flowmeter cannot be used for vapours or gases, or non-conducting liquids. Installation is comparatively simple since upstream pipe layout hardly affects it. Typical applications are to pulp and paper mill stocks, cement slurry, sewage, crushed ores, crystallizing liquors and food pulp.

Rotating propellers

In the fourth paper Mr F. R. Allen points out that the propeller flowmeter has been used for many years but owing to the power needed to transmit the spindle motion through a gear train only medium and larger sizes were formerly fitted. But electrical methods of detecting the propeller rotation have removed this limitation and considerably widened the application. A strong impetus to development came from the aircraft industry since propeller flowmeters are compact and light, but applications in the process industries have been growing recently.

Such devices consist (Fig. 5) of a short length of pipe housing a coaxial multiblade rotor mounted in low friction bearings. Various methods are available for detecting the rotor movement whilst subjecting it to minimum restraint:

1 *Rotating magnet*. A permanent magnet is housed in the rotor and induces alternating current in a coil located outside the housing.
2 *Reluctance type*. One or more coils and a fixed magnet are arranged around the meter. The rotor is of magnetic material, which, in revolving, varies the reluctance of the magnetic path. This induces an e.m.f. in the associated coils connected in series, thus summating the e.m.f.'s.
3 *Photoelectric systems*. The rotor interrupts a photoelectric light source and detector. (Very limited application in industrial plants.)

The meters described cover flows from 0·1 to 20,000 i.g.p.m. in sizes from 0·25 in. to 16 in.; the output at full scale is about 1 V and rangeability up to 20 : 1. Pressure drops are 1·25–6 lb/in², depending on meter size. Manufactured in light alloy or stainless steel, the body designs are suitable up to 3000 lb/in² and for −200 to +500 deg C. Speed of response is very high but the fluid must be clean and viscosity allowed for.

Allen describes electronic equipment associated with the meters, giving typical circuit diagrams. These cover the measurement of both instantaneous rate of flow and totalized flow, together with arrangements for alarms, flow ratio, batching, etc. Correction for density of flowing liquid is available, either manually or automatic. Systems for detection are essentially based on pulse counting for totalizing with averaging techniques for instantaneous rate of flow display. Possible basic methods are pulse scaling by valve binary counters, cold-cathode multi-element Dekatron tubes and diode pump circuits. The latter two systems were described in detail together with the means for density correction which may be automatic from a measured value or based on temperature. Allen mentions possibilities of multi-channel presentation together with totalization and difference measurements. He suggests applications in the batch control of liquids, blending of fluid products and other similar fields.

Solving the pulsation problem?

Among topics raised in the discussion of the papers on 27th January that of pulsating flow measurement created much interest. Clearly all the methods described are basically suitable for such service although precautions would sometimes be necessary. As linear devices they could at least give a true average flow measurement. The Chairman commented that these developments offered a possible solution of many outstanding problems of industrial flow measurement caused by pulsation.

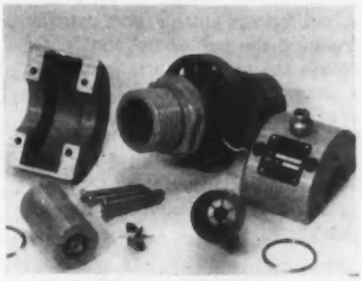


Fig. 5 The component parts of a propeller flowmeter

Other speakers pointed out that none of the methods offered any real advance in the measurement of large gas flows; the difficulties of using an ultrasonic meter on gases or vapour seemed very great and ionizing a gas for its measurement in a magnetic meter did not seem practicable. Neither did the new methods hold much promise for the measurement of local flows in large volumes of liquids.

Discussing magnetic meters, several users gave their experiences: the error due to a nearly closed gate valve on the inlet, problems due to eccentric build-up of solids in the tube, and some difficulties in design of electrode systems for temperatures of 300 deg C and pressures of 2000 lb/in².

Pick-off *by 'UNCONTROLLED'*

WHAT makes the Physical Society Exhibition so attractive a show? Probably three things: its small size, the absence of garishness, and the ability to discuss instruments and their applications with scientific staff who really know what they are talking about. Such staff can be more easily spared for this exhibition than for many others since it lasts only four days. One might be tempted to add absence of crowds and the general public, but this year, I am told, the afternoons, especially Wednesday and Thursday, were very full. Between 3 and 4 p.m. on the Wednesday 1555 people passed through the turnstiles of the two Halls. The total attendance was up about 5000 on last year. I only had time to get to Vincent Square for a short time one morning, but was impressed by the amount of really new equipment that was on show. I also liked having the book and magazine exhibits in the main body of the New Hall instead of in the gallery, although I gather there were mixed feelings among those actually manning the publishers' stands. Of course the two hall arrangement is a snag, and with record numbers of exhibitors (152) and visitors, there will be a renewed demand to move the show elsewhere. But I for one hope it is left where it is; Olympia or Earls Court would destroy its character.

FOG and ice did not deter some seventy-five guests—out of the instrument, aircraft and g.w. world—from reaching Cranfield on 14th January to enjoy the dinner of the third annual guided missile course at the College of Aeronautics. The course, which started in October last, is no longer for NATO officers only, as in previous years, but for those from 'NATO and like-minded countries'. Swedish and Indian officers are being instructed in g.w. technology, and at the dinner Switzerland's Captain Grossenbacher, as elected head of the course, proposed the toast of the College in a speech showing an artful command of English humour. Sir Frederick Handley Page, the Chairman of the College's Governors, was also in genial form, all the more so as he found himself proposing his own health. But he was not enthusiastic about space travel, believing that we should use science to extend the range of vision of our eyes rather than the range of transportation of our bodies. This dinner, as the College Principal, Professor Murphy, pointed out, has become an important day in the Cranfield calendar. It is also something of an old boys' reunion, for many students of the two earlier courses were present; I was glad to meet one from Belgium who is an enthusiast for CONTROL, especially as I hear from the Editor that some more g.w. articles will be appearing soon.

LORD TEMPLEWOOD in a recent broadcast recalled the Government official who had a saddle installed in his office because his mind worked better when he was on horseback. Mine often works best in a train, but I doubt that a seat of railway moquette and a hinged arm rest would give much stimulation in the office. Rhythmical noise and movement, whether hoof or wheel produced, is surely the mainspring of the effect. Absence from incoming telephone calls undoubtedly assists, and I trust that when British Railways have the money to introduce a radiotelephone service on inter-city trains they will keep it one way.

Office saddles and 'non-smokers' may be facetious, but a real point is that many firms do not allow enough scope to creative individuals to work in surroundings that quicken their minds. Human engineers are now being brought in to help in design of control panels; perhaps the next move should be to use their services in the design of laboratories where control system engineers work.

TALKING of laboratories, I like the colourful decoration of the new ones of the British Scientific Instrument Research Association at Chislehurst, which were formally opened by Professor Mott on 7th January. Not a human engineer but SIRA's Deputy Director, Dr Maddock, was responsible for the detailed design. The arrangement of rooms and furniture is very flexible, and the gas heating installation is interesting in having a time switch and two thermostats—one for normal open-loop control by outside temperature and one as an emergency frost control.

At the lunch which followed the opening, I was slightly surprised to hear Dr Thomson, the Director of SIRA, say that the Association hopes to be free of DSIR support in about six years' time. Admirable though it would be to save the taxpayer money in this way, there will surely be more and more calls for applied instrument research in the future. Whatever funds the industry can supply, they are unlikely to finance all the worthwhile research projects that could be undertaken. DSIR now supports 47 industrial research associations, and I understand that the number will probably increase. The new laboratory itself owes much to DSIR's backing, who have doubled the donations made by some forty of SIRA's member firms to a special Building Fund. Nevertheless, the Association at present faces a deficit of some £14,000 on the cost of the building; the Building Fund is still open, and other firms may like to subscribe to it.

I AM intrigued to learn that a four-year sandwich course on *Applicable* Mathematics is now in progress at the College of Science and Technology in Chelsea (where more appropriate for educational artistry?). I suspect the name reflects the views of Dr Bronowski, who is on the College's advisory committee: 'mathematical rigour will be insisted on, but as a means to an end, and not . . . as an end in itself.' But the course gives me the germ of an idea. Why not a four-week course for production engineers on *Instrumentable* Plant and Machinery?

SOME of us who read both of England's serious Sundays were mystified on 1st February to see two differing versions of Mr Leon Bagrit's admirably reasoned views on the threat of Russian automation. I gather Mr Bagrit was asked independently to write an article for the *Observer* and to give an interview to the *Sunday Times*. Independently? Well . . . And competition between the two papers being keen, it is good to know that automation reports are rated so important. But four years ago automation in Britain was news; to-day it is fear of automation elsewhere. Mr Bagrit strikes at the issue's crux, when, coining a new word, he says: 'Today, if a market is lost due to a competitive automated process, it will be very difficult indeed to "out-automate" our competitors quickly enough'.

NEWS ROUND-UP

from the world of control

£24 million alliance

The 30th January 1959 saw the long-awaited marriage of 50-year-old British Tabulating Machine and Powers-Samas Accounting Machines (43), daughter of Vickers Ltd. The happy couple, now to be known as International Computers and Tabulators Ltd—ICT—start life with net tangible assets worth £M23·8. Powers' parents, Vickers, have a 38% interest in ICT and this is reflected in the composition of ICT's Board; of 16 directors, ten are ex-BTM and six ex-Powers. Sir Cecil Weir, who was BTM's Chairman, now chairs ICT, and the two Deputy Chairmen are Col A. T. Maxwell, who chaired Powers-Samas, and H. W. Stammers who was BTM's Deputy Chairman.

CONTROL understands that ICT will continue the GEC relationship via the jointly-owned company, Computer Developments Ltd, and also the rather more nebulous relationship with Ferranti. It will be recalled that the Powers-Samas Pluto data-processing system was built around a Ferranti Pegasus.

ICT Directors face world competition: left to right, Mead (BTM), Maxwell (Powers-Vickers), Weir (BTM), Stammers (BTM), Hird (Powers-Vickers)

Why merge?

The reasons for the merger are fairly obvious. As ICT Chairman Weir said, 'it is to create a great British company which has the resources to compete in any market, with any other company in the world, in the field of mechanical, electro-mechanical, and electronic machines applied to accounting, statistical, management and production control problems.' CONTROL suspects that America's giant International Business Machines provides the most powerful competition facing International Computers and Tabulators.

—— AIRCRAFT ——

More integration?

The news that Smiths Aircraft Instruments and Kelvin & Hughes are to collaborate with Sperry Gyroscope '. . . in certain projects for aircraft control and instrumentation . . .' looks like yet another temporary marriage of convenience aimed at obtaining a fair slice of the contracting market for aircraft equipment. The resources of both organizations '. . . are being applied, in the first instance to the development of a flight control and instrumentation system for new British civil aircraft, in particular to the de Havilland 121. Proposals are also in hand for similar systems for future military aircraft.'

– DATA HANDLING –

Digital storage discussion

As expected, the discussion at the SIT's Symposium on digital storage media (*News Round-up*, last month) was fairly lively. Questioners did not, however, seem to be particularly biased in favour of any one system, the general consensus of opinion being that each storage medium has its own particular field of application, although there is a great deal of overlap. Powers-Samas' (now part of ICT with British Tabulating Machine) D. F. Nettell had no great difficulty in defending punched-card storage. A single punched card can hold up to 80 decimal digits; thus it can represent a single transaction making it particularly valuable for industrial work where, say, one punched card can hold a complete formula.

An upstart medium

Benson-Lehner's 'Digitape', which was described by E. J. Petherick, was jocularly referred to as an 'upstart medium'. It is unproved, of course, but its cost is so low that it is likely to bring simple digital data handling into new fields. Digitape's application would appear to be where large numbers of fairly simple recorders are required. Petherick told CONTROL that Benson-Lehner have been discussing possible applications for Digitape recorders in terms of thousands. The cost of Digitape is around 2s 6d per million bits, compared with 5s for punched cards and punched tape, and 10s or more for magnetic tape. Whether these figures really mean anything is another matter; magnetic tape is, of course, re-usable, and, in any case, there is no suggestion that Digitape can compete with magnetic tape.

Accurate data transmission

The punched-tape approach was described by M. E. Theis of Creed. His medium is so well known and proven over many years of service that no defence was necessary. Its excellent transmission characteristics make it ideal for transmitting digital data to a remote point for processing. Theis told CONTROL that this is a one-way traffic; unlike teleprinting where the operator reads his own signals, the transmitted information is regenerated at the remote station and transmitted back to the originator. The originator sees the information which the recipient has received and not the information which he, himself, transmitted. This makes for extreme accuracy.

D. W. Willis of Decca Radar, who covered the magnetic tape approach, met no opposition. As Willis told CONTROL 'We were hoping for a scrap, but nothing happened'. Magnetic tape's high speed of operation and versatility make it particularly suitable for commercial data processing, and it can be erased for re-use. There was some suggestion that there might be a field for low-speed magnetic tape equipment. Willis said he had considered this but could get little support from users.

——EXPORTS——

Door-to-door delivery

Several German manufacturers have received proportioning controllers—100 in

all—from West Instruments by direct delivery. These were sent by shooting brake on a door-to-door basis, and J. A. Hartnett, West's Managing Director, says that not only was the possibility of damage during normal shipment overcome and urgent production schedules met, but, furthermore, delivery costs were about 10s less per instrument than normal charges. The vehicle crossed by the Dover Ferry, drove overland to Troisdorf and Düsseldorf and returned six days later. The instruments will be incorporated in plastics machinery for the temperature control of machine barrels.

British computers for USA

A breach has been made in the powerful American computer market by Elliott-Automation, four National-Elliott 802 transistorized digital machines having been ordered by US firms. The machines are to be incorporated into industrial data-processing systems in oil refineries, chemical plants, power stations and steel mills. All the indications are that further orders will be placed this year. CONTROL can only assume that the simplicity, flexibility and—presumably—the price of the 802, were overwhelmingly more attractive than the quite natural American desire to buy American.

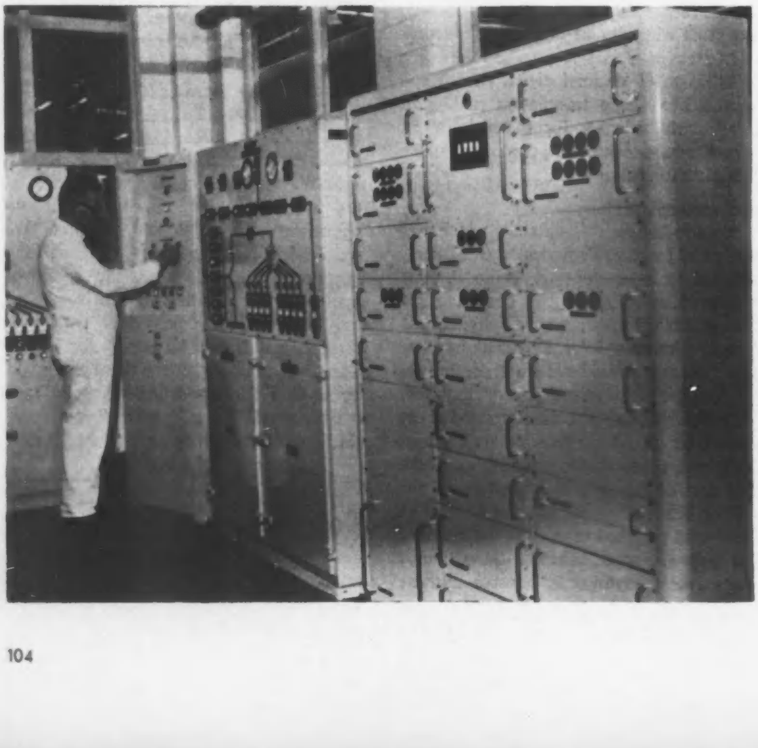
FOOD

Automatic weighing

Last month, CONTROL visited McVitie & Price, the biscuit firm, who have an advanced plant at Harlesden. Automatic techniques are used to a large extent and the plant is believed to be one of the most up-to-date in Europe. Much of the operation is by standard Henry Simon equipment, but one or two innovations have been made recently, including an EMI 'Emiway' automatic weighing system which has just been installed.

In the basic 'Emiway' a transducer is fitted on the back of the scale and coupled directly to the pointer shaft. The main cabinet, which may be remote from the scale, incorporates servo equipment and a digitizer which converts scale pointer shaft angle to a digital code representing angular displacement. This digital information is decoded at high speed and in such a fashion that rapidly varying movements of the pointer can be followed. The output may be continuously displayed and, by means of coincidence circuits, the output of the decoder can be 'caught' at a predetermined setting, and made to control, say, the feeding mechanism of the material being weighed. Any number of such circuits can be added to perform various functions; for example, the coarse and fine feeding of several different materials on a cumulative weighing system.

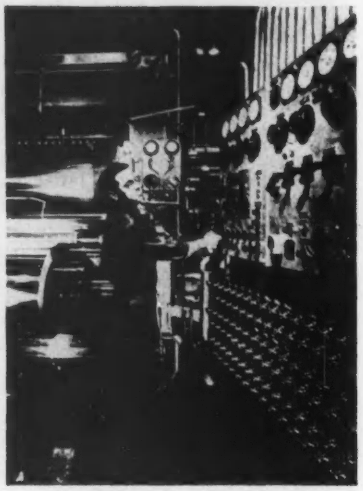
Main control room at McVitie & Price; Emiway automatic weighing equipment on right



METALS

Novel control at Kaiser Aluminum

The 100-in. five-stand hot strip mill at the Ravenswood, USA, plant of Kaiser Aluminum & Chemical has been equipped with rather unusual control equipment by US General Electric. Each of the five mill drives, five screwdown drives, two winding reels, and delivery pinch roll and side trimmer, have individual adjustable-voltage controls, and the mill stand and reel controls are tied together by a coordinating regulating system. According to USGE, this system offers several advantages: a coordinated current limit stop and reverse jog feature minimizes scrap; reels are arranged for extensive automation of the threading, stopping and unloading processes; all stand screwdowns can be operated from a common switch, with descending speeds from the entry to the delivery end of the mill; the speeds of individual stands are varied automatically to take up inter-stand slack at the start of a coil, to hold inter-stand looper arms in a fixed position during running and to increase inter-stand tension for gauge correction during tailing.



72-in. foil mill at Kaiser Aluminum has X-ray gauge controlled screwdowns

USGE have also developed the control system for a 72-in. two-stand cold strip mill at Ravenswood. The screwdowns on this mill are operated by automatic gauge control equipment on information from X-ray gauges.

METEOROLOGY

Met Office's Mercury-Meteor

The solution of atmospheric mathematical equations by numerical methods, and the prediction of the state of tomorrow's atmosphere from its state today, will be the job of a Ferranti Mercury digital computer which has been installed by the Air Ministry Meteorological Office. The Met Office have named the machine 'Meteor' and will feed it directly with observations received by teleprinter at Dunstable. It will not be used in the routine day-by-day preparation of forecasts until after a lengthy period of research.

Typhoon tracking with an IBM 704

An IBM 704 computer is on its way from New York to the Japanese Meteorological Agency in Tokyo where it will be used for daily weather prediction, including the tracking of typhoons—a serious problem in the Japanese islands. The US Weather Bureau are already able to make good weather forecasts 48 hours in advance, with the aid of digital computers.

IN BRIEF

● **Cobalt-platinum magnetic alloy** 'Platinax II', a powerful permanent magnet material which is workable before heat treatment, is available from Johnson, Matthey.

● **Keelavite Hydraulics** have appointed Elettro Tecnica Apparecchiature (ETA) as their agents in Italy for the sale of hydraulic installations and units.

● **Convention on Thermonuclear Processes**—basic physics, British experiments (Zeta I, Sceptre III and linear pinch), construction of Zeta I, design problems for future Zetas, direct conversion from nuclear to electrical energy—has been arranged for the 29th and 30th April by the Institution of Electrical Engineers.

● **Induction heating furnaces** (mains frequency) for aluminium holding, to the value of $300,000 were ordered some months ago by an American firm from Wild-Barfield. A further order has now been placed.

● **High frequency transistors** by Semiconductors Ltd have been reduced in price some 15 to 20%, with additional discounts for large quantities.

● **Pressure pickups** by Consolidated Electrodynamic Corp, USA, are to be manufactured by Solartron.

● **Preformations Ltd**, a new company for the manufacture of cast permanent magnets of high energy ('Magloy'), has been formed by Plessey, following an agreement with Arnold Engineering Co, USA. Located at Swindon, Preformations are directed by A. G. Clark (Chairman), A. E. Underwood and Robert M. Arnold (USA).

● **BTR Industries** (thermoplastics and rubber) are to acquire Microcell (aircraft engineering, plastics and electronics).

● **Instrumentation and control** schemes (pneumatic or electronic) will be available in complete form from James Gordon & Co (Sales Director: R. Hussey) now that the Power Plant Division of Elliott Bros has been amalgamated with Gordon.

● **Reactor control and instrumentation** course to be held at Harwell from 7th to 17th July inclusive. Details from The Principal, Reactor School, AERE, Harwell, Berks.

● **Electro-polishing** stainless steel by immersing it in an electrolyte and passing a current through it, the workpiece acting as the anode, is carried out by Electropol Processing Ltd of Farnham, Surrey.

● **Transistors** having cut-off frequencies up to 750 Mc/s and power dissipations of 750 mW have been announced by Texas Instruments Inc, USA.

● **Sunvic Controls'** London office is now Crown House, Aldwych, London, WC2; TEM 8040.

● **Data processing system** IBM 7090, a transistorized digital computer said to be the most powerful data processing system yet to be marketed commercially by IBM, is to be installed at the UKAEA.

● **Emidec 1100** integrated data-processing system should be doing clerical work at ICI Plastics Division in March 1960.

● **Cambridge Instrument's** new 20,000 sq ft laboratory in Cambridge should be complete in June.

● **Photomultiplier tubes;** Mullard point out that their new range of pm tubes consists of one 15-stage, five 11-stage and two 10-stage tubes, and not, as stated in *Quick Look* last month, one 15-stage and two 10-stage tubes.

● **Alfred Imhof's** telephone number is now Uxbridge 6231.

● **The ILU Translations Bulletin,** now published monthly by DSIR, gives details of USSR research and information on the availability of Russian translations.

● **Atomic Energy Division** formed by Teddington Aircraft Controls has C. D. Boadle as Technical Manager and C. R. Peter as Liaison Executive.

● **Totally-enclosed motors,** ¾ to 2 h.p., in '66' frame dimensions (BS 2048) are available from Newman Industries.

● **Saro-Nuclear Enterprises Ltd** is the name of a nuclear engineering (applied irradiation and industrial isotopes) company formed by Saunders-Roe and Nuclear Enterprises (GB).

● **Electronic Components Centre** members, Ardente Acoustic, George Bray, British Electric Resistance, Cosmocord, EMI Electronics, Gresham-Lion, Hunt (Capacitors), London Electric Wire Co and Smiths, Painton, and Telegraph Construction and Maintenance will exhibit together at the Hanover Fair (26th April to 5th May, 1959).

● **EEA quit RIC.** The Electronic Engineering Association (ex-Radio Communication and Electronic Engineering Association) have given up their membership of the Radio Industry Council.

● **Electrical Instrument Test Service** under NPL supervision has been set up by BSIRA, for manufacturers and users of electrical instruments.

LOOKING AHEAD

A diary for the next three months

Unless otherwise indicated, all events take place in London. BCS British Computer Society. BritIRE British Institution of Radio Engineers. IEE Institution of Electrical Engineers. IMechE Institution of Mechanical Engineers. JIE Junior Institution of Engineers. RAeS Royal Aeronautical Society. SIT Society of Instrument Technology

MONDAY 16–TUESDAY 17 FEBRUARY
Specialist Discussion Meetings on New Digital Computer Techniques Committee of the Measurement and Control Section IEE At the Institution

TUESDAY 17 FEBRUARY
Simulation of Melting Shop Operations on a Computer R. Neate BCS 6.15 at the Northampton College of Technology, EC1

THURSDAY 19 FEBRUARY
Theoretical Studies of Guided Missile Control Systems E. G. C. Burt RAeS 6.00 at the Institution of Civil Engineers, Great George Street, SW1

Gyroscopes in Automatic Controls T. N. Dewey and H. E. Stephenson IMechE 6.30 at the Institution

TUESDAY 24 FEBRUARY
Symposium on Automatic Weight Control in Industry SIT 6.00 at Manson House, Portland Place, W1

FRIDAY 27 FEBRUARY
Computers and Materials Handling W. J. Kease and A. O. Quarterman JIE 7.00 at 14 Rochester Row, SW1

THURSDAY 5 MARCH
Symposium on the Use of Data Recorded on Industrial Plant SIT 6.00 at Manson House, Portland Place, W1

WEDNESDAY 18 MARCH
Approach to Learning and Teaching Machines C. E. G. Bailey BCS 6.15 at the Northampton College of Technology, EC1

THURSDAY 19 MARCH
Long Range Missiles E. C. Cornford RAeS 6.00 at the Institution of Civil Engineers, Great George Street, SW1

WEDNESDAY 25 MARCH
Papers on Radio Telemetry BritIRE 6.30 at the London School of Hygiene, Keppel Street, WC1

MONDAY 6–THURSDAY 9 APRIL
16th Annual Radio and Electronic Components Show, organized by the Radio Electronic Component Manufacturers' Federation to be held at Grosvenor House and Park Lane House, W1 Admission by invitation only

TUESDAY 7 APRIL
Symposium on Large Capacity Storage Systems BritIRE 6.30 at the London School of Hygiene, Keppel Street, WC1

THURSDAY 16 APRIL
Self Optimizing Control System for a Certain Class of Randomly Varying Inputs A. P. Roberts SIT 6.00 at Manson House, Portland Place, W1

THURSDAY 16–THURSDAY 30 APRIL
22nd Engineering, Marine, Welding and Nuclear Energy Exhibition, Olympia

TUESDAY 21 APRIL
The Problem of Maintenance of Electronic Equipment in the Process Industries (Discussion) IEE 5.30 at the Institution

MONDAY 27 APRIL
The Electronics of Guided Missiles RAeS 6.00 at the Institution of Civil Engineers, Great George Street, SW1

LOOKING FURTHER AHEAD

WEDNESDAY 17–SATURDAY 27 JUNE
International Plastics Exhibition and Convention Olympia

WEDNESDAY 1–SUNDAY 5 JULY
Television Engineering in Science, Industry and Broadcasting BritIRE 1959 Convention at Cambridge

PEOPLE IN CONTROL

by Staffman

HALL SMITH YOXALL
Welcoming international cooperation?

THAT THE BRITISH INSTRUMENT INDUSTRY should work together is, I think, accepted by most of us, but Royal Dutch/Shell's instrumentation chief, **H. Landeweer,** would go much further. He wants cooperation to extend beyond national frontiers. Responding for the Guests at the BIMCAM annual luncheon, he suggested large-scale international cooperation so that manufacturers may coordinate development and standardization. Rather a bitter pill for the individualistic instrument manufacturer.

ICI Deputy Chairman, **Sir Ewart Smith**—looking rather forbidding in my photograph—called for more manufacturer-user cooperation. On the left is an apparently happy user, RAeS President **Sir Arnold Hall.** The cigar smoker is BIMCAM President **L. S. Yoxall.**

Both Smiths and Sperry Gyroscope are setting their respective houses in order, presumably because of increased competition ahead. I understand that decentralization is the main objective of the reorganization at Sperry Gyroscope. Three separate operating divisions—Brentford, Bracknell and Industrial—under Managing Director **Robert Broadbent,** have been announced by Board Chairman **Arthur Hillier. J. C. G. Bell,** at Brentford, will cover aeronautical and marine activities and Bracknell's **H. B. Sedgfield** will concentrate on g.w. and inertial navigation. The Industrial Division, which reflects Sperry's growing interest in industrial control, will be managed by ex-Chief Engineer **M. L. Jofeh.** Other Industrial appointments include **D. Burns,** Sales Manager and Manager, process control, **W. G. Lisle,** Manager, machine systems, **D. McNaught,** Manager, electromechanical components, and **F. G. Bradbury,** Manager, hydraulics.

BROADBENT
3-phase breaker

POTTER
Accumulator

WALTERS
Cook-general

STEWARD LORKIN
Divide and rule

The Smith Group have formed Smiths Aviation and Marine Divisions from Smiths Aircraft Instruments, Smiths Industrial Instruments, Waymouth Gauges, David Harcourt, Kelvin & Hughes and the Smith aviation interests. The new Divisions will be responsible to a coordinating Board consisting of Chairman **Ralph Gordon-Smith** (Chairman and MD of S. Smith & Sons), Managing Director **G. B. G. Potter** (Kelvin-Hughes' MD), and Directors **L. A. Morgan** (Director and GM of Smiths Aircraft Instruments), **H. M. Samuelson** (Tech Sales Director, Smiths Aircraft Instruments) and **G. S. Sturrock** (Commercial Director, Kelvin-Hughes). I asked Managing Director Potter for his views on the future of control and instrumentation. 'Automatic control of aircraft must come . . . , as for industrial control, it's the old story of costs; when steam pressures can be held within 2 or 3% automatically, compared with 20 to 25% by manual control, the automatic system must win.'

Hearing that Sunvic's domestic products Sales Manager, **C. E. Walters,** had been appointed General Sales Manager for all Sunvic products, I asked him about the likely expansion in the company's domestic and industrial business. 'The domestic market has an upper limit', said Walters, 'but we have by no means reached this yet. The market for instrumentation, data processing and logging, etc, however, will continue to grow'. Sunvic Sales Managers are: **R. Lloyd,** scientific and industrial; **J. M. Anderson,** pneumatic instruments; **W. J. Donnelly,** data processing. Contracts Section Manager is **E. C. Bird.**

S. F. Steward's appointment as Director-designate of BEAMA has meant his resignation from Lancashire Dynamo Holdings where he was Joint MD with **D. C. Lorkin**—now sole MD. I recall that Lancashire Dynamo's Chairman, **Lt-Col G. S. Marston,** was appointed in August last. **R. A. Bent,** Lancashire Dynamo Electronic Products' MD, has joined the Board. **K. A. Robinson** becomes Chief Engineer, his place as Chief Development Engineer being taken by **W. F. Hill.**

ASHTON DAVIES
An eye on the future

HOLTON
No 19th-century thinker

David Ashton Davies (ex-Marconi Instruments, Mullard and British Physical Laboratories) has joined EMI Electronics as Sales Manager, Instruments. According to David 'EMI have an eye on the process control market'. **Charles Kramskoy** becomes Chief Engineer of EMI Electronics' Commercial Division. Kramskoy helped develop the Emidec 2400 computer.

Peter Holton, who left EMI to take charge of 20th Century's photomultiplier advisory service, feels that '19th-century thinking on measurements is on its way out'. He tells me that pm tubes may soon be able to count individual light quanta! So much for the lumen.

ADVERTISER'S ANNOUNCEMENT

Tick **No 70** on reply card for further details

Electrical Aids in Industry *Data Sheet* **No.1**

Electro-Heat

The ways in which electricity can be used to advantage in industry are many and varied. Some are well known but others are not known well enough. For this reason the Electrical Development Association has prepared a series of detailed data sheets on various applications which will be printed in this journal from time to time.

This Data Sheet is the first of a number devoted to electro-heat–that is, heat produced by electricity for the processing and treatment of materials. Other uses will be dealt with later on in the series.

There is an unalterable physical law that the efficiency of conversion of *electrical* energy to *heat* energy is 100 per cent. The same cannot be said of the efficiency of combustion of any solid or liquid fuel.

All the applications of electro-heat have these advantages in common :—

1 Electro-heat is clean both in regard to its application and the method of generation.

2 It can easily be controlled more precisely than any other form of heat, manually or automatically.

3 It can be brought to the job instead of having the job brought to it.

4 It permits better use of floor space and the elimination of unnecessary handling.

5 In many of the newer processes it is the only possible form of heat which can be used.

6 It often ensures a higher quality of products with fewer rejects.

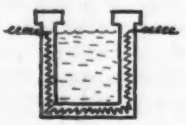
7 It gives the best working conditions.

8 It reduces or eliminates fire and explosion hazards.

Below will be found brief notes on some of the various methods of generating heat by electricity.

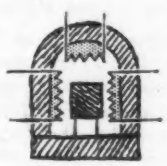
Resistance Heating

This is the best known form of electric heating. The elements provide a high resistance to the passage of electricity and thus heat is generated. It can be used in furnaces for melting or heat treatment of any material whether metal or not, or the resistance of the workpiece itself can cause the generation of heat.



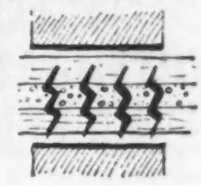
Induction Heating

Eddy currents are induced in the surface of a conducting workpiece, heating it up. The depth to which this heating will penetrate is determined by the time it is given.



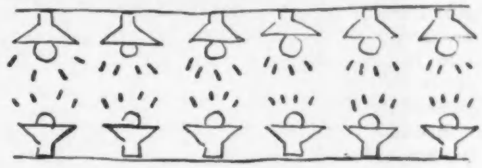
High-frequency Dielectric Heating

This form of electro-heat can be used only on non-conducting materials such as wood, plastic and rubber. The material is placed between two electrodes to which a high voltage is applied at a high frequency. This has the effect of generating heat inside the material rapidly and uniformly throughout its entire thickness.



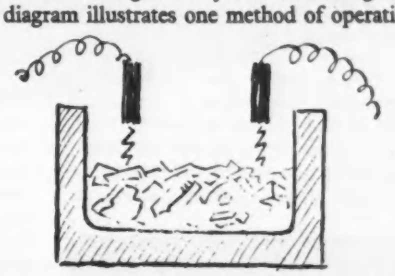
Infra-red Heating

This method employs pure radiant heat. The bulk of the radiation takes place in the infra-red portion of the radiation frequency spectrum. The heaters may take the form of reflector lamps or sheathed wire elements. The method is extremely flexible and has many uses, including paint drying and pre-heating plastics.



Arc Melting

This form of heating is chiefly used for melting steel. The diagram illustrates one method of operation.



Very large charges can be melted; melting units of 200 tons capacity are now in operation.

The Application of Electro-Heat

All these methods of electric heating can be applied in almost an infinite variety of ways. Some of these ways will be dealt with in subsequent sheets.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2.

Excellent reference books on electricity and productivity (8/6 each or 9/- post free) are available—"Induction and Dielectric Heating" is an example; "Resistance Heating" is another.

E.D.A. also have available on free loan a series of films on the industrial use of electricity. Ask for a catalogue.

CUT HERE

New for Control

A monthly review of system components and instruments

PIPE COUPLING

for elevated temperatures

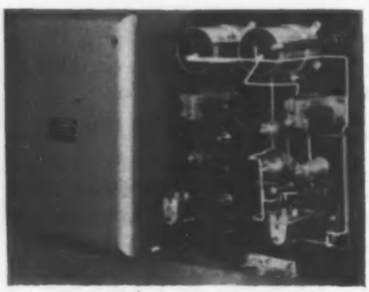
The design of pipe joints and couplings for use at elevated temperatures has to a great extent been dictated by the availability of suitable resilient gasket materials. Conventional asbestos impregnated materials and metallic reinforced gaskets are limited to a temperature range in the proximity of 400 deg C, and not all offer corrosion resistance to a variety of chemicals. King Aircraft Corporation have made available a pipe coupling for elevated temperatures which has been developed and tested at pressures up to 6000 lb/in^2. The Conoseal is based on the V-band clamp principle and consists of a male and female flange and metallic gasket. The flanges are suitable for either lap or butt welding to the pipe line or duct. The standard range offered covers pipe bores from ¾ to 10 in. Non-standard couplings have been manufactured up to 36 in. diameter.

Tick **No 169** on reply card

PROTECTION RELAYS

for phase failure and undervoltage

Protection is required in many cases against phase failure and under voltage occurrence; with certain motors this has become a necessity. In 3-phase systems a relay designed to operate only on failure of one phase does not always provide satisfactory protection. The motor may continue to run under these circumstances and the relay will not operate owing to the polyphase voltage generated by the motor which may burn out. A number of Londex equipments have been designed to solve this problem.



One of the protection relays with its cover removed

The relay unit (type LF/PF) is suitable for 1-phase or 3-phase 4-wire systems. Maximum voltage that can be accepted is 440 V a.c. or 250 d.c. For 3-phase 3-wire systems a resistance unit, providing a dummy neutral, is available. The relay will operate when the voltage of one phase drops by 30% of the nominal supply value or fails completely. Up to 2 sets of contacts can be provided on each relay rated at 4 A 250 V a.c. These can be arranged to perform the required duty, e.g. to trip the motor contactor by opening a no-volt circuit, or closing a trip circuit on a main circuit breaker.

The relay unit (type KR/PF) is similar in operation to the LF/PF unit but can also cater for 3-phase 3-wire systems. The unit will operate when the supply voltage falls by 10% and is capable of detecting failure of one or more phases. The unit is normally set to an under voltage figure of 15% and to automatically reset at 98%. Maximum voltage that can be accepted is 550 V a.c. The unit is available in a single phase version and in addition equipments can be made to incorporate delay circuits to ensure that the controlling relays operate on maintained voltage reductions only and not on spurious fluctuations.

Tick **No 170** on reply card

LOAD CELL

long term accuracy of ± ¼%

The Nobel load cell is claimed to give extreme stability against temperature effects, long term drift of the cell output and creep with sustained loading. An electrical weighing installation can utilize these load cells to give an accuracy of ± ¼%, maintained over a long period. The cells are designed to withstand considerable overload, and the effects of non-axial loading are minimized by the load cell housing which is constructed to carry side loads comparable with the maximum rated load of the cell. Since the cell contracts less than 0·01 in. under full load, weighing is inherently fast, and the mechanical structure of the weigher can be greatly simplified. Six standard types of cell covering weights up to 100,000 lb are available.

The load cell has been produced by Ericsson Telephones Ltd in conjunction with ICI Ltd.

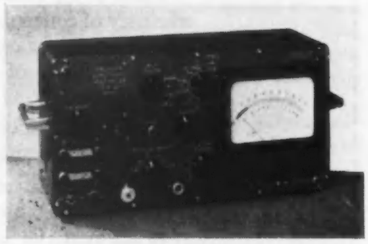
Tick **No 171** on reply card

ELECTRONIC MULTIMETER

called Eric it does a little better

The Eric electronic multimeter is to be marketed by Metrix Instruments Ltd. Voltage, current, resistance and other measurements which would normally be possible only with electrometer or vibrating capacitor circuits are made possible by a symmetrical three-terminal circuit using conventional valves. The circuit presents an input impedance of either 10^{14} ohm or zero as required. The output impedance of the circuit is virtually zero and feeds an amplifier and meter with the facility for connecting an external recorder.

The circuit design is such that a high degree of stability is achieved, and when a voltage is applied in the memory position (a polystyrene capacitor is switched across the input circuit) the instrument retains the reading for at least twelve hours after disconnecting the source with less than 1% drift. Small voltage variations can be made with full-scale discrimination regardless of absolute value using an external capacitor with guard-ring. The capacitor is connected in series with the source and is first charged to the source voltage by short-circuiting the input to the instrument. When the short-circuit is removed the voltage across the instrument is initially zero and records only variations of the source voltage. By using a constant voltage source, the hysteresis losses of capacitors can be measured in a similar manner. The basic ranges of the instrument are: 0·05 V to 2 kV, $0{\cdot}5 \times 10^{-7}$ to 2×10^{3} A, 1–2 × 10^{10} ohm. A range of adaptors extends the range to 35 kV, $0{\cdot}5 \times 10^{-10}$ A 10^{13} ohms. Other accessories include VHF probe, analogue integration adaptor, Coulomb-meter adaptor, pH meter attachment. The price is £239.



A high degree of stability is claimed for Eric

Tick **No 172** on reply card

DIFFERENTIAL TRANSFORMER

a linear accurate transducer

The Schaevitz linear variable differential transformer is a device for the accurate measurement of mechanical quantities. The basic transformer is an electro-mechanical transducer which produces an electrical output proportional to the displacement of a separate movable core. It consists of a number of coils axially spaced on a cylindrical coil former, with a rod-shaped magnetic core positioned inside the coil assembly providing a preferred path

a NEW

HIGH SPEED PANEL MOUNTING ELECTRO-MAGNETIC COUNTER

NOW

with

INSTANT

ELECTRIC RESET

This counter embodies all the well tried features of our Type 100 Electric Counters, plus electric reset. This form of reset is particularly useful where a number of counters are required to be reset at the same time.

Coils for both resetting and counting can be supplied for operation on the following voltages:—24/48 volts D.C., 110/115 volts A.C. 50 and 60 cycles and 230/250 volts A.C. 50 cycles. A further model is now available with improved push button manual resetting facilities which ensure that the counter is virtually sealed.

Write for full details

Counting Instruments Ltd

★ ***This counter can be supplied with the first wheel graduated 0 to 9 or 0 to 11 as standard.***

COUNTING INSTRUMENTS LTD, 5 ELSTREE WAY, BOREHAM WOOD, HERTS Tel: ELStree 1382 (4 lines)

for the magnetic flux linking the coils. The transducer is available in an extremely comprehensive range of sizes.

The plot of output voltage versus displacement will not deviate from a straight line drawn through the origin by more than

An amazingly compact transducer

0·5% of the output at full linear range (for a standard transformer within the linear range). The output voltage is stepless. The characteristics of the smallest transformer (Series M 005 M–L) in the linear standard range have been given below as an example. Linear range 0·005–0–0·005 in. Transformer: diameter $\frac{3}{16}$ in.; bore $\frac{1}{8}$ in.; length $\frac{3}{8}$ in. Core: diameter 0·108 in.; length 0·180 in. Primary resistance 55 ohm. Total secondary resistance 85 ohm. Weight (without core) 3·24 g. Core weight 0·12 g. Sensitivity (mV/0·001 in./V in) is 0·335 (400 c/s) and 4·53 (20,000 c/s) into a 0·5 megohm load. The total output with nominal voltage input (3 V) is 0·005 V at 400 c/s and 0·068 V at 20,000 c/s.

The Schaevitz Engineering transformer is to be marketed in the UK by British Arca Regulators Ltd. Later they will manufacture it under licence.

Tick No 173 on reply card

SPECTROMETER
for tracing leaks

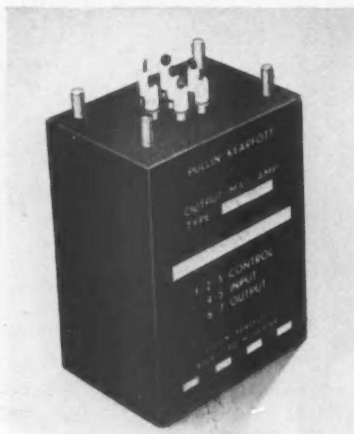
Helium is used as the leak detection medium in the Helitest separately magnetized spectrometer. The detector unit is capable of tracing one part helium in five million parts air. To detect leaks in a closed system, the vessel is evacuated down to 1/10 mm Hg and a fine spray of helium is passed over the outside of the vessel. When gas comes near an aperture it is drawn into the system and carried through to the detector, which immediately announces the presence of the helium. Using the vacuum method it is possible to test leaks of 10^{-10} atmos/sec, i.e. less than 10^{-7} lusec. Another method is to pressurize the system under test with a gas containing helium; the suspected surfaces are probed with an aspirating nozzle connected to the detector. Helium is chosen as the tracer because it is rare in the atmosphere, is non-explosive, non-toxic and does not desensitize the detector. The pumping group is protected by an electromagnetic valve against insufficient vacuum or pressure surge. The detector is being introduced by Appleby & Ireland Ltd on behalf of their French associates, Laboratoire des Basses Pressions.

Tick No 174 on reply card

MAGNETIC AMPLIFIERS
for 2-phase servomotors

A range of output magnetic amplifiers designed to provide control phase power for size 10, 11, 15 and 18, 400 c/s 2-phase a.c. servomotors is being offered by R. B. Pullin & Co Ltd. The input signal to the amplifier may be provided from a valve or transistor pre-amplifier and for high temperature operation the range is claimed to be satisfactory to 125 deg C. A more economical range of amplifiers is available for the ambient temperature range − 65 to + 70 deg C.

The characteristics of the RH.601 amplifier have been given below as an example of the range. This amplifier is suitable for a size 15 motor. Primary voltage 115 V. Rated load impedance (unity power factor) 2640 ohms. Maximum voltage output into rated load 115 V. Primary current at rated output 0·13 A. Quiescent control coil current 4 mA/coil. Control coil resistance 3360 ohms/coil. Control coil by-pass capacitor 0·1 μF.



A completely encased amplifier

Tick No 175 on reply card

SERVO AMPLIFIER
a miniature, transistorized unit

Another new product from Pullin is their miniature transistorized servo amplifier. This has been designed to provide the control phase power for size 10 servomotor (R 124–G) or the size 10 high performance motor generator (R 807–G). With care it can drive a suitable size 15 motor. No additional heat sink is needed to operate in ambient temperatures up to 60 deg C. The power supply is 26 V 400 c/s a.c. with centre tap or 20 V d.c. The input signal is the error from a synchro chain; and the output is up to 4 W into a 10 − 0 − 10 V motor winding. The amplifier gain can be set by setting a resistor between the terminals, and facilities are provided for using feedback and setting the amplifier to the required performance conditions.

Tick No 176 on reply card

PULSE GENERATOR
possesses stable amplitude

Although designed primarily for accurate measurement of pulse height analyser channel threshold and width, a new precision pulse generator from Sunvic Controls Ltd may be of value in other applications in which a shaped pulse of stable and accurately known amplitude is required. The instruments consist of three main sections: stabilized power supply, voltage divider network, and pulse forming network. Pulse amplitude is adjustable over the range of 0 − 40 V by the main control and there is also incremental control which provides continuous variation over a range of 0 − 1·2 V with a linear accuracy of $\pm$ 2 mV. Overall amplitude stability during an 8-hour period is better than $\pm$ 0·05% (allowing for mains variation of $\pm$ 5%). A three-position switch selects pulse widths of 1, 5 or 25 μsec. Pulse polarity may be either positive or negative at a repetition rate equal to mains frequency.

Tick No 177 on reply card

TRANSPORT LAG SIMULATOR
aid to process analysis

The Elliott Brothers (London) Ltd distance-velocity or transport lag simulator (type ND461) is an instrument designed for use in conjunction with analogue computing equipment for the representation of large transit time effects which occur in a number of industrial processes, usually associated with the flow of fluids in ducts. The transport time provided by the instrument can be varied between 2 and 60 sec, and is inversely proportional to the magnitude of an electrical input signal, so that it may be either preselected to a constant value, or caused to vary in relation to other plant parameters represented in the computer. The input and output signals corresponding

The simulator is basically a 100 position motor-driven switch having two wipers

Tick **No 72** on reply card for further details

PNEUTECHNIQUE

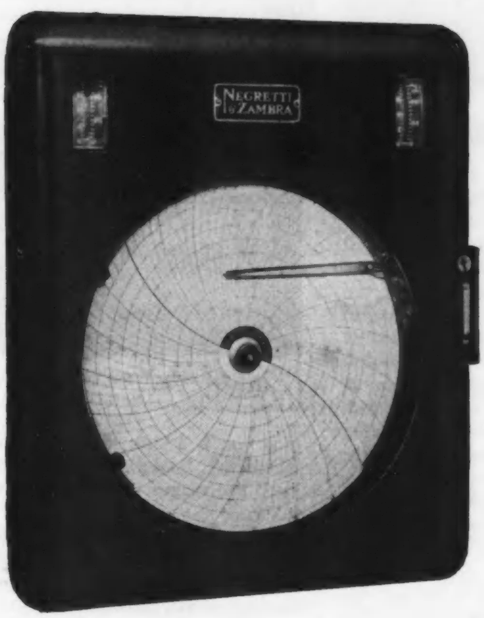
3 automatic compound controllers give greater flexibility, more accurate control

These Negretti & Zambra Compound Controllers fulfil the definite need in industry for flexible, accurate automatic control. Operating on a clean, dry air supply at 20 p.s.i., they make automatic control of industrial processes easy, rapid, and convenient. In all three models the various units are standardised—so a model selected for a particular application can be readily adapted to others.

1 **BASIC CONTROLLER :** ***for use when manual control is not required.***

2 **CONTROLLER :** ***incorporating facilities for manual control internally.***

3 **CONTROLLER :** ***with auto/manual test facilities mounted externally on a sub-panel.***



Set-up procedure is extremely simple — a particular advantage where it is necessary to close down the plant periodically, as resumption of automatic control can be rapidly effected. Further advantages are:

- **NO INTERACTION BETWEEN TERMS,** ***enabling the controller to embrace wider plant characteristics than are possible with interacting controllers.***
- **IDEAL BASIC CONTROL RESPONSE** ***generated under all conditions.***
- **TRUE VALUES** ***of Proportional Band and Integral and Derivative Action Times are calibrated on the various units.***
- **OPTIMUM PLANT CONTROL** ***can be methodically and rapidly effected.***
- **TRULY CALIBRATED PLUG-IN UNITS** ***allow easy replacement without re-setting and facilitate servicing.***
- **EASILY CONVERTIBLE** — ***thus a two-term controller may be used with either Derivative or Integral Unit, and three-term controller with both units.***
- **SELF-CONTAINED UNITS,** ***compact and self-purging. FORCE-BALANCE PRINCIPLE of operation involves no levers and friction losses, the diaphragm assemblies giving high sensitivity.***

• • •

We will be pleased to send you a copy of our fully illustrated booklet No. R 35/2 on your request.

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to the transported information may be in the range $\pm$ 100 V; and between d.c. and the cut-off frequency which is dependent upon the transport time. Between these limits the output amplitude and phase are independent of the signal frequency content.

The instrument consists basically of a 100 position motor-driven switch having two wipers one of which is connected to the output of a 'writing' amplifier, and the other to the input of a 'reading' amplifier. The motor, whose speed is servo-controlled, drives the switch continuously in one direction, via a reduction drive, the time taken for one complete revolution being equal to the distance-velocity lag. To each of the 100 fixed contacts is connected a 22,000 $\mu\mu$F polystyrene capacitor, which are successively charged to the 'writing' amplifier output level as the switch rotates. The two wipers are close together on a rotating arm, the leading wiper 'reading' the voltage to which the capacitors were charged by the 'writing' wiper during the previous revolution, after which operation the capacitors are recharged by the training 'writing' wiper to new levels which are stored for a further revolution time.

The output signal, which appears as a number of discrete voltage steps, represents the input signal delayed in time by between 3 to 60 sec determined by the speed of rotation of the switch.

Tick **No 178** on reply card

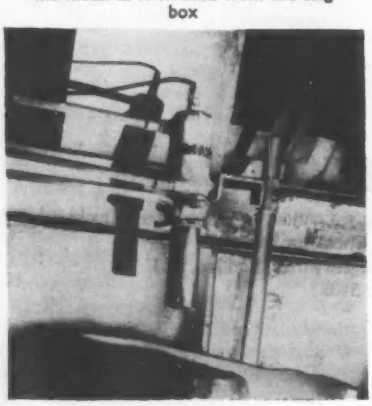
RADIATION PYROMETER

uses photocell

A radiation pyrometer has been developed which will measure the temperature of the metal as it leaves the cupola or holding furnace, with an accuracy which it is claimed is equal to that of an immersion pyrometer. The pyrometer uses a photocell, can be focused on a small target (about 1 in^2) and is sighted on the metal stream in the slag box. The pyrometer lens is protected by a heat-resisting glass window. A water jacket is supplied with the instrument to keep its temperature below 40 deg C. The pyrometer (type RP18) is made by Land Pyrometers Ltd.

Tick **No 181** on reply card

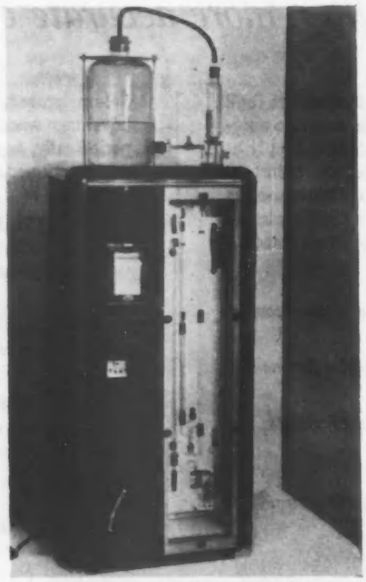
The pyrometer is shown sighted on the metal as it streams from the slag box



POLAROGRAPHIC and SO_2 ANALYSIS

two useful instruments

Mervyn Instruments have recently shown the Mervyn-WRPL polarographic electrode. This was developed by the Water Pollution Research Laboratories whilst carrying out investigations into the characteristics of flowing liquids. It is claimed that the wide-bore, dropping-mercury electrode helps in polarographic methods of analysis for the following reasons: it gives increased sensitivity, operates continuously; covers a wide range of flow rates; automatic temperature control can be incorporated; and that alternative reference electrodes can be fitted.



The sulphur dioxide recorder is housed in a most presentable cabinet

Another new instrument by the same firm is an automatic sulphur dioxide recorder. This is based on an instrument designed at the Central Electricity Authority Research Laboratories, who are concerned with the amount of sulphur dioxide pollution that is caused by the smoke from power stations. In extreme cases the high sulphur dioxide concentration which exists in smog conditions can cause serious illness; and even a concentration of 50 parts per 100,000,000 is exceedingly unpleasant.

The range is 0 – 80 parts/10^8 but this can be extended. The sensitivity is $\pm$ 1 part/10^8 and the accuracy $\pm$ 2 parts/10^8 maintained over many years without recalibration. The output is on a continuous paper tape, 3½ in. wide. The dimensions are 4⅓ × 2 × 1⅔ ft and the power consumption is 300 W.

Tick **No 182** on reply card

ELECTRONIC POTENTIOMETER

simplicity is the keynote

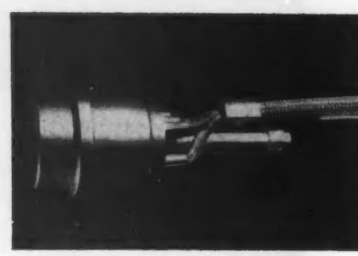
The new electronic potentiometer from Electroflo Meters Co Ltd is a high-speed continuous balance null type instrument, designed to register low-potential electrical values from signal sources such as thermocouples, resistance thermometers, flowmeters, strain gauges, shaft position indicators, etc. The potentiometer is available as a single point recorder; a recorder with multiple alarm switching; a controller-recorder with two-step or proportional action; and as a recorder-converter with pneumatic transmission signal of 3-15 lb/in^2. It is claimed to be the most simple mechanism achieved in industrial potentiometer design; this because the total motion is exercised through a single shaft which is mounted in ball races, and the recording pen and indicating pointer as well as the control and multiple alarm switching, proportional sender, pneumatic converter and coding number are directly and positively related.

Tick **No 183** on reply card

PRESSURE TRANSDUCER

continuous operation at 600 deg F

A new pressure transducer is claimed to be the first that is capable of continuous operation at 600 deg F. At this temperature gauge pressures of from 100 to 5000 lb/in^2 can be measured. It will also operate down to – 350 deg F and can withstand static accelerations up to 100 *g* in any direction. The all-welded internal construction enables the transducer to operate without cooling at 600 deg F, but this can be extended to 2000 deg F by a special adaptor. The output is 20 mV nominal (18 mV minimum). The excitation is 5 V d.c. or a.c. (r.m.s.) and the carrier frequency is 0–20 kc/s. The input and output impedance is 350 ohms $\pm 5\%$.



This picture of the pressure transducer is about actual size

The transducer is being manufactured in the UK by the Solartron Electronic Group Ltd under licence from the Consolidated Electrodynamics Corporation, USA.

Tick **No 184** on reply card

QUICK LOOK

The NSF-union miniature hermetically-sealed relay type M is designed to achieve reliability under extreme environmental conditions of high acceleration, severe mechanical shock and working temperatures from —65 to +125 deg C. The relay has a balanced rotary type armature, rotating on an axis which passes through the centre of gravity of the relay, switching

a maximum of six change-over circuits. It is filled with an inert gas to prevent contact corrosion, and is manufactured by NSF under licence from Westinghouse Brake and Signal Company Ltd.
Tick **No 185** on reply card

The Londex LF **relay** is now available in a plug-in form. An 18-way plug and socket is used.
Tick **No 186** on reply card

A liquid **level controller** has been put on the market by Liquid Systems Ltd. It has been designed primarily to maintain a constant level in the fountain solution tray of lithographic presses, but it can be used with all types of liquids. The liquid supply is from a 1 gallon polythene bottle.
Tick **No 187** on reply card

A range of toroidal **voltage regulators** has been announced by Foster Transformers Ltd. Three of the four basic sizes are in production. All units are designed for a nominal ratio of 240/270 V or 240/240 V. The rated current range covered in the four sizes is 2·5 to 40 A.
Tick **No 188** on reply card

The latest addition to the Edwards High Vacuum Ltd Spedivac range is the F 1203 **fractionating oil diffusion pump.** This fills the gap between the 9 and 16 in. models, and means that the pumps are available in a complete series of sizes from 2 to 24 in. bore, with speeds between 80 and 12,000 litres/sec.
Tick **No 189** on reply card

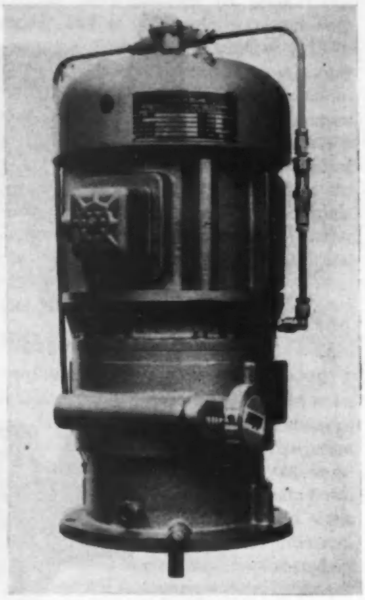
A **tube tester** for non-magnetic metals has been produced by CNS Instruments Ltd for the rapid location of faults in tubes of non-ferrous metal of stainless steel, and for locating corrosion of condenser tubes in steam boiler installations.
Tick **No 190** on reply card

A range of **pneumatically-operated valves** to control hydraulic presses and similar machinery has been announced by Hunt & Mitton Ltd. The two-pressure hydraulic throttling valves have a neutral position and are suitable for operation by manual pilot valves or by an electric timer. They are suitable for oil or water at pressures up to 4000 lb/in² (non-shock) and are made in sizes ⅜ to 3 in.
Tick **No 191** on reply card

An **edge-lit indicator** (1¼ × 4⅜ × 1⅞ in.) has been introduced by the Aircraft Components and Connector Division of Thorn Electrical Industries Ltd. The unit can be supplied for 4, 6, 12, or 28 V a.c. or d.c. A high level of illumination is provided by using an Atlas midget panel lamp as the light source. Numerals from 0 to 9 with a decimal point are incorporated.
Tick **No 192** on reply card

A resistance welding **current meter** claimed to have no upper limit to the value of current that can be measured has been designed by Hirst Electronics Ltd. Standard instruments have a minimum of 500 A and a maximum of 100,000 A over 6 scales. The minimum pulse time is 10 msec but pulses down to 2 msec can be measured if several welds are repeated.
Tick **No 193** on reply card

Counting Instruments Ltd have announced that their **electric counters** (type 100) can now be supplied with **electrically-operated** resetting facilities. The coils for **resetting** and counting can be supplied for operation on 24/28 V d.c., 110/115 V a.c. and 230/250 V a.c.
Tick **No 194** on reply card



The first vertical Kopp

A vertical version of the Kopp **variable speed gear** has been produced by Allspeeds Ltd. Previously the standard model was suitable only for horizontal mounting. The size is limited at the moment to between ½ and 5 h.p. with a standard stepless speed variation over a 9 : 1 output speed range.
Tick **No 195** on reply card

INDUSTRIAL PUBLICATIONS

Recent amendments and additions are available for the Kelvin and Hughes **Components Catalogue.** 196

Chamberlain and Hookham describe and illustrate their induction pattern **protective relays** for instantaneous over-, reverse, and under-power protection, and for over-voltage and under-voltage protection. 197

Variable speed gears is the subject of a Kopp booklet: diagrams, descriptions and data. 198

A Negretti and Zambra publication on **pressure gauges** emphasizes that with a Bourdon tube movement or a diaphragm movement they can cover all range requirements. 199

A complete catalogue and price list in a folder is available from **Airmec.** 200

Ferranti have produced a general interest booklet on their range of **computers, data processing systems** and allied services. In more detail: a brochure on the Pegasus 2 and a temporary leaflet on their new process control transistor computer. 201

A small sample length of **cog gear belt** and **high speed transmission belt** made by the American Russell Manufacturing Co is included in a pamphlet from their UK agents, Graton and Knight. 202

Daystrom Ltd briefly describe their **Heathkit** printed-circuit valve voltmeter kit. 203

A loose leaf catalogue of their complete range is issued by **Cawkell Research and Electronics** 204

The latest **Commander** spare parts list from George Kent: chart-drive units (mechanical and electrical). 205

Fuses and fuse equipment, made by the Swiss firm H. Schurter (UK agents Dekko Cameras) are listed in their catalogue sheets: French-German text, English summaries. 206

From High Pressure Components Ltd: sheets on their pilot-operated **control valve** and gauge **protection valve.** 207

An official booklet (price 3s.) lists the wide range of special courses in **higher technology,** management studies and commerce available in London and the home counties. 208

A new leaflet from Carter Gears outlines their hydraulic variable speed **gears** with handwheel controls. 209

A technique for moulding small **thermoplastic components** is illustrated by George Goodman Ltd. 210

For further information on any industrial publication tick the corresponding number on the prepaid reply card facing page 129.

For your bookshelf

Stepping after von Neumann

Mathematics and Logic for Digital Devices** by **James T. Culbertson
Van Nostrand. 1958. 234 pp. £1 16s. ★ 232

The author makes great claims for this book. After referring to the advent of the digital computer, he says, 'Much of the mathematics required for its use and operation is not yet included in the standard curriculum. Here we will supply some of the material, especially the mathematical logic. We have tried to include whatever mathematics will be especially useful to the prospective worker in the general field of digital computers.' The publishers tell us that Dr Culbertson has combined teaching in the mathematics of digital computers with extensive research in biophysics and psychology. But he has evidently never designed a digital computer. If he had, he would not discuss such components as binary adders, using terms taken from physiology (*receptor*, *neuron*, etc) rather than electronic terms. Such usage makes what is, in any case, an abstract discussion appear entirely remote from reality. Neither would anyone with experience of computer design consider that, in order to understand the small amount of Boolean algebra which designers of switching circuits sometimes find useful, one must make a thorough study of traditional logic, including syllogisms, the algebra of classes, and the rest.

However, I must admit that Dr Culbertson can claim that he is but following in the footsteps of von Neumann, who undoubtedly made handsome contributions to the subject of logical design in its early days. Moreover, his book is well written and interesting to read. I would not, however, recommend his approach to the subject to a young student wishing to study digital computers seriously, with a view to becoming a programmer or a design engineer. He would do much better to start at once on the study of programming and computer design.

M. V. WILKES

Random signal for system research

Principles and Applications of Random Noise Theory** by **J. S. Bendat
John Wiley: New York. Chapman & Hall: London 1958. 452 pp. £4 8s. ★ 233

This book is an advanced text on random signal theory from the first principles in statistics and probability. The original works of Rice and Wiener in this field are covered and extended to include unpublished material of the author.

The growing necessity for the use of random signals, both theoretically, and in practice in the laboratory, by control system research engineers, has resulted in a spate of new textbooks on this subject written by mathematicians for engineers. This is one of them.

Very little of the book deals specifically with control systems as opposed to the more general problem of analysing or deliberately modifying the properties of the random signal itself. In particular no mention is made of the large amount of published work on non-linear control systems subjected to random signal inputs. This is a technique which is proving to be the best approach for obtaining true operating demands and performance, and permitting optimum values of critical parameters to be determined.

There are ten chapters covering different topics; the sixth on analogue computer techniques could with advantage have been left out. The chapter on exponential cosine autocorrelation functions shows how a wide range of natural phenomena can be characterized by this simple correlation function.

Some fifty pages are devoted to the errors in correlation techniques. This is a very important subject and is well handled. It is timely too as more and more engineers begin to

use these statistical methods. The last chapter, on the zero-crossing problems, is also outstanding.

It is doubtful if the student (as claimed), or even the raw graduate could utilize this book, but it should prove of value to the research worker, both as a source book of recent American work and as a mathematical foundation for engineering approximation and analysis. JOHN L. DOUCE

Standard work

***Transistor Technology, Vols. II and III** edited by F. J. Biondi Van Nostrand. 1958. Vol II: 714 pp. £6 11s. 6d. Vol III: 430 pp. £4 14s.* ★ 234

The first volume in this set of three on transistor technology tended to have a historical approach but the last two volumes bring the subject as up to date as possible with this rapidly moving subject.

Vol II takes up the problem of growing and purifying single crystals of silicon and extends the information given in Vol I* on germanium. It sets out the general principles of transistor and diode operation and design and gives practical examples. Triodes, tetrodes and field effect devices are described. This volume also discusses the use of semiconductors in detecting atomic radiation and the conversion of solar energy into electrical power by silicon photocells. Lastly, there is an interesting chapter on surface conditions and their effect on transistors and diodes.

The semiconductor technologist is acquiring a large number of tools with which to put his ideas into practice and Vol III describes many of the methods used to prepare junctions, which include alloying, growing, diffusion and evaporation. Information on the chemistry of etching and cleaning junctions is also given. The concluding chapter discussing the measurement of transistor and diode characteristics and reliability is especially interesting. Although the surfaces of transistors are sensitive to ambient conditions and may become contaminated, considerable advances have been made in encapsulation since the early days of transistor design, and it now seems that transistors will definitely become more reliable than thermionic valves. Figures in Vol III show that several millions of hours of life may be expected before failure: in fact, in hearing aid applications, 870 million hours is quoted as the average life.

The volumes are excellently produced with many diagrams and references to original papers. They form at present the best standard text on semiconductor technology.

M. SMOLLETT

* Reviewed in CONTROL, September 1958

Books received

Transform Method in Linear System Analysis by John A. Aseltine. McGraw-Hill. 1958. 316 pp. £3 6s. ★ 235

Punched Cards: Their Application to Science and Industry (2nd edition) edited by R. S. Casey and others. Reinhold: New York. Chapman & Hall: London. 1958. 704 pp. £6 0s. ★ 236

Health in Industry by D. Hunter. Penguin Books. 1959. 288 pp. 4s. 0d. ★ 237

Principles of Automatic Controls by Floyd E. Nixon. Macmillan. 1958. 420 pp. £1 10s. ★ 238

The Solid State for Engineers by Maurice J. Sinnott. John Wiley: New York. Chapman & Hall: London. 1958. 532 pp. £5 0s. ★ 239

Scientific and Learned Societies of Great Britain (59th edition). George Allen & Unwin. 1958. 215 pp. £1 15s. ★ 240

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